OSU-APEX-03002 (Revision 0)

OSU APEX-1000 Test Facility Description Report

Manuscript Completed: May 12, 2003

Prepared For

U.S. Department of Energy
Germantown, Maryland

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LIST OF ACRONYMS

ACC	Accumulator
ADS	Automatic Depressurization System
AP600	Westinghouse Advanced Passive 600 MWe
AP1000	Westinghouse Advanced Passive 1000 MWe
APEX	Advanced Plant Experiment
ASME	American Society of Mechanical Engineers
BAMS	Break and ADS Measurement System
CL	Cold Leg
CMT	Core Makeup Tank
CVS	Chemical Volume Control System
DAS	Data Acquisition System
DP	Differential Pressure
DVI	Direct Vessel Injection
FMM	Magnetic Flowmeter
FVM	Vortex Flowmeter
HL	Hot Leg
HPS	Heated Phase Switch
HX	Heat Exchanger
IRWST	In-Containment Refueling Water Storage Tank
LC	Load Cell
LDP	Differential Pressure Level
LOCA	Loss-of-Coolant Accident
LT	Level Transducer
MFP	Main Feedwater Pump
NIST	National Institute of Standards and Technology
NRC	Nuclear Regulatory Commission
OSU	Oregon State University

LIST OF ACRONYMS (cont.)

P&ID	Piping and Instrumentation Diagrams
PLC	Programmable Logic Controller
PORV	Power-Operated Relief Valve
PRHR	Passive Residual Heat Removal
PT	Pressure Transducer
PZR	Pressurizer
RCP	Reactor Coolant Pump
RCS	Reactor Coolant System
RNS	Normal Residual Heat Removal System
RPV	Reactor Pressure Vessel
SBLOCA	Small-Break LOCA
SCR	Silicon Controlled Rectifier
SG	Steam Generator
TF	Fluid Temperature
TH	Heater Rod Temperature
TR	Thermocouple Rod
TW	Wall Temperature
WT	Wall Thickness

1.0 INTRODUCTION

The Oregon State University (OSU) Department of Nuclear Engineering has modified its Advanced Plant Experiment (APEX) for assessing the AP1000. APEX is a unique, world-class, thermal-hydraulic integral system test facility, which has been used to assess the performance of the passive safety systems of the Westinghouse AP600. The data obtained using the APEX facility has been an essential part of the AP600 Design Certification Program. APEX is the best geometric representation of the AP1000 and is the only facility in the world currently capable of assessing the long-term cooling capability of the AP1000 passive safety systems.

OSU has successfully performed 75 integral system tests in the APEX facility for Westinghouse and the United States Nuclear Regulatory Commission (NRC). These tests are of high quality and are being maintained by OSU, Westinghouse, and the NRC. The successful development and operation of this unique integral system test facility has given the OSU thermal-hydraulic research team extensive expertise in instrumentation, quality assurance, and testing.

The APEX test facility, shown in Figure 1-1, has been specifically designed and constructed to provide high quality data for use in computer code benchmark calculations. The test facility is a one-fourth height, one-half time scale, reduced pressure integral systems facility. Significant modifications were made to the facility to perform testing on the AP1000. These include new reactor heater rods to increase the maximum facility power from 600 kW to 1000 kW. In addition, the pressurizer and core makeup tanks were increased in size, passive core cooling system injection line resistance was reduced, and the fourth-stage Automatic Depressurization System (ADS) valves and associated piping were increased in size to provide larger Reactor Coolant System (RCS) depressurization capacity. A formal scaling analysis was performed to ensure that the facility accurately represents the AP1000 plant.

Table 1-1 lists the APEX modifications required for the AP1000 testing program. The objective of this report is to provide a comprehensive description of the APEX-1000 test facility. The intent is to provide code modelers with the information needed to accurately model the APEX-1000 experiments. This report provides a description of the RCS; the passive safety systems; the instrumentation, controls, and power systems; and the balance-of-plant components. Complete sets of facility isometrics and piping and instrumentation diagrams (P&IDs) have also been included. The following systems are included in the test facility:

- *Reactor Coolant System*: This includes an electrically heated 48-rod bundle core, a reactor vessel with internals, two hot legs, four cold legs, two 133 U-tube steam generators (SGs), a pressurizer (PZR), and four reactor coolant pumps (RCPs).

- *Passive Safety Systems:* This includes two core makeup tanks (CMTs), two accumulators (ACCs), a four-stage ADS, a passive residual heat removal (PRHR) heat exchanger (HX), an in-containment refueling water storage tank (IRWST), and portions of the lower containment compartments.

- *Balance of Plant:* This includes a feedwater system, non-safety grade Chemical Volume Control System (CVS) and an active Residual Heat Removal System. The geometry of the interconnecting pipe routings was also duplicated.

All of the RCS components are constructed of stainless steel and capable of consistent operation at 400 psia (2.76 MPa) while at the saturation temperatures. All primary system components are insulated to minimize heat loss.

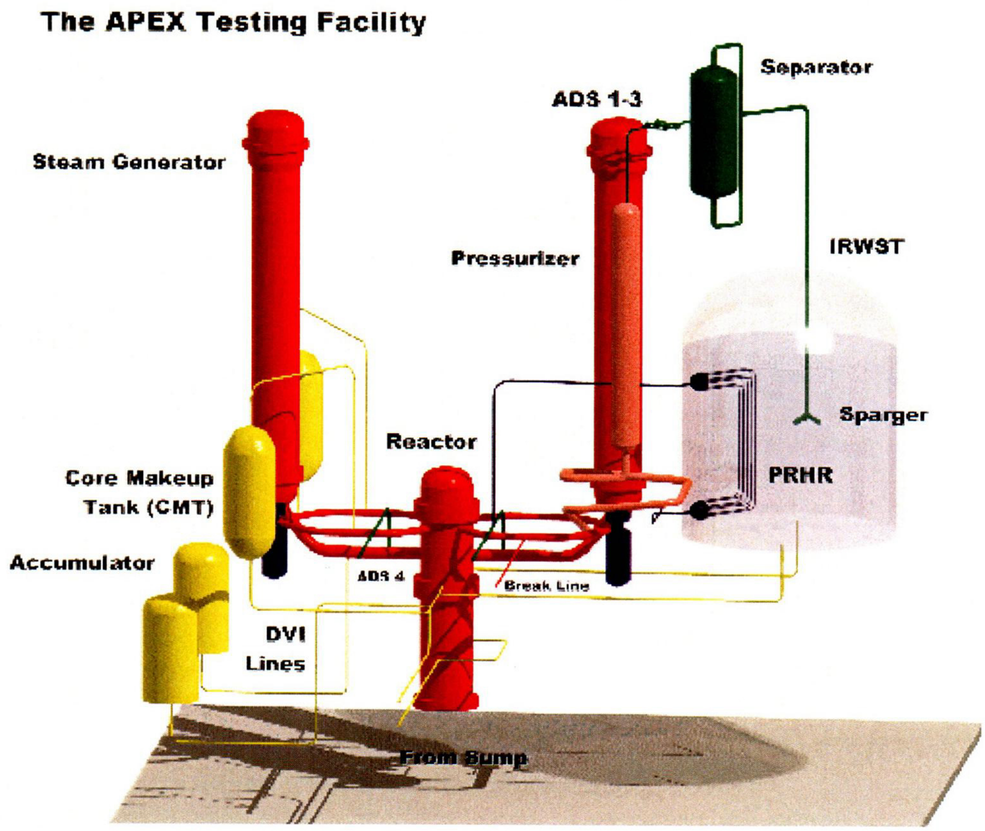

Figure 1-1 APEX Facility Layout

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Table 1-1 Modifications to APEX Required for AP1000 Test Program

Component	Modifications to APEX
Reactor Power	Increase core power by 67% (limited to 1MW maximum)
PZR	Increase pressurizer volume Reduce pressurizer surge line diameter
SG Heat Transfer Area	No change required for testing
RCP Flow	No change required for testing
CMTs	Increase CMT volumes by 25% Reduce line resistance to 64% of original value
ACCs	No change required for testing
IRWST	Increase IRWST level
ADS Stages 1-3	No change required for testing
ADS Stage 4	Increase ADS-4 flow area by 76% Reduce line resistance to 28% of original value
PRHR HX	Increase PRHR flow capacity by 74% by reducing line resistance. No change in surface area/tube number required for testing
Containment	Raise sump curb height
Passive Containment Cooling System	Not part of APEX testing program

2.0 REACTOR COOLANT SYSTEM (RCS)

The APEX facility RCS is a complete model of the AP1000 Nuclear Steam Supply System (NSSS). The RCS includes the reactor pressure vessel (RPV), PZR, two SGs, four RCPs, and associated primary loop piping. See Figure 2-1 and Figure 2-2 for an elevation view and plan view of the RCS, respectively.

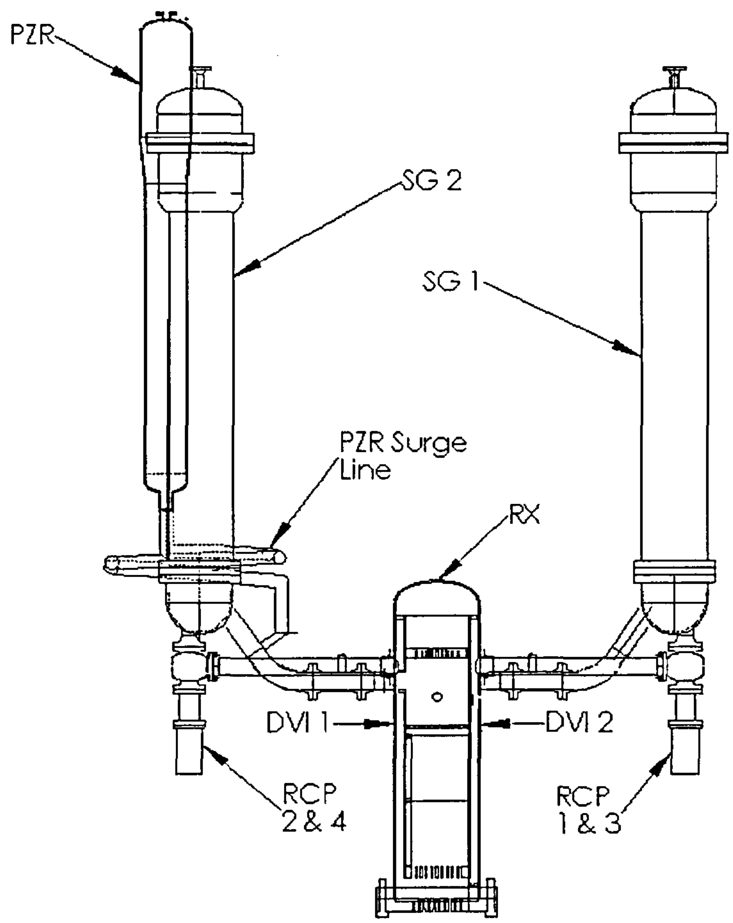

Figure 2-1 Elevation View of Reactor Coolant System

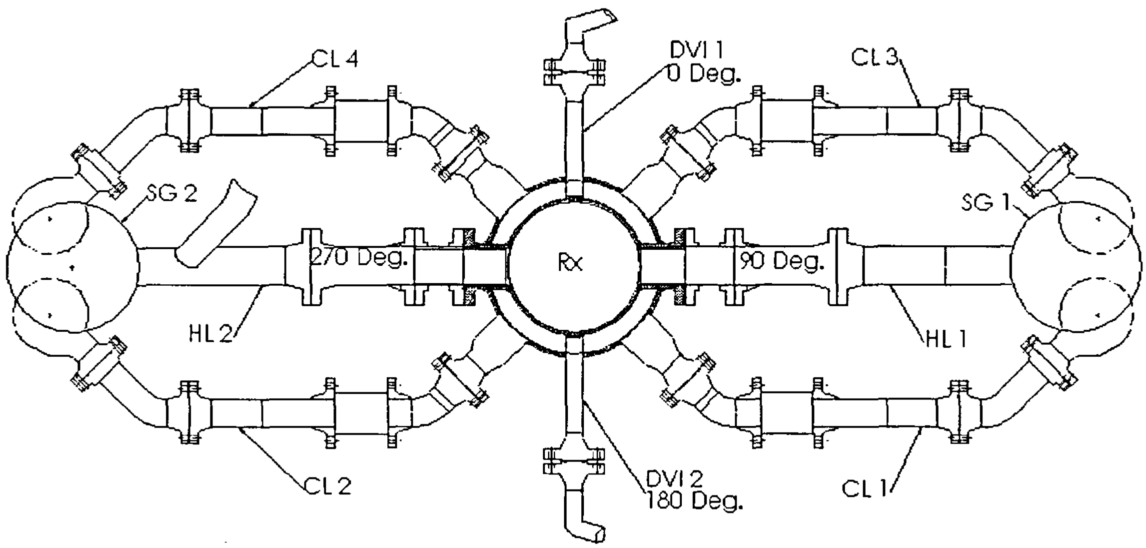

Figure 2-2 Plan View of Reactor Coolant System

2.1 Reactor Pressure Vessel (RPV)

The RPV models the upper and lower internals of the AP1000 reactor vessel, core barrel, downcomer, and core. The maximum core power is approximately 1000 kW and can be distributed in two radial power zones and can be programmed to simulate time-dependent decay power. The RPV includes connections for the two hot legs (HLs), four cold legs (CLs), and two direct vessel injection (DVI) lines.

During normal operation, cold water enters through four [ ]^{a,b,c} cold legs into an annular downcomer region that is bounded by the inside surface of the reactor vessel shell and the outside surface of the core barrel. The cylindrical reactor vessel shell is fabricated from SS 304 plate having a [ ]^{a,b,c} outside diameter (O.D.), and a [ ]^{a,b,c} wall thickness. The core barrel extends from the upper head flange down to the lower core plate, and has a 19 in. I.D. with a [ ]^{a,b,c} wall thickness and is made of SS 304. The downcomer gap is [ ]^{a,b,c}.

The cold water in the downcomer flows into the lower plenum, a cylindrical fluid volume region bounded vertically by the lower core plate and the lower head plate. The [ ]^{a,b,c} thick lower head plate is bolted to the carbon-steel reactor vessel flange that is welded to the cylindrical reactor vessel shell. The fluid changes direction in the lower plenum and travels upward through holes in the lower core plate into the core. The lower core plate is [ ]^{a,b,c} thick and [ ]^{a,b,c} in diameter. The upper vessel head is a 2:1 elliptic head having a [ ]^{a,b,c} I.D.

The heated zone of the core extends [ ]^{a,b,c} from the top of the lower core plate. The core consists of 48 heater rods, each having a [ ]^{a,b,c} diameter, and 5 fluid thermocouple (T/C) rods. Six of the heater rods have a T/C located at the disc end (top) of the heater. In addition to the heater rod T/Cs and the individual fluid T/Cs in the RPV, there are five T/C rods that measure the axial fluid temperature distribution in the core. All of the heater rods penetrate the lower head plate, the lower plenum, and the lower core plate to create a heated zone between the lower core plate and the upper core plate (see Figure 2-3). Two spacer grids are provided for support of the heaters, one at the mid-plane of the heaters and the other near the core exit. The heater bundle is surrounded by a reflector/baffle that directs the fluid through the core (see Figure 2-4). The reflector is filled with PUROCast™ (ceramic) to minimize the heat capacity of the core region.

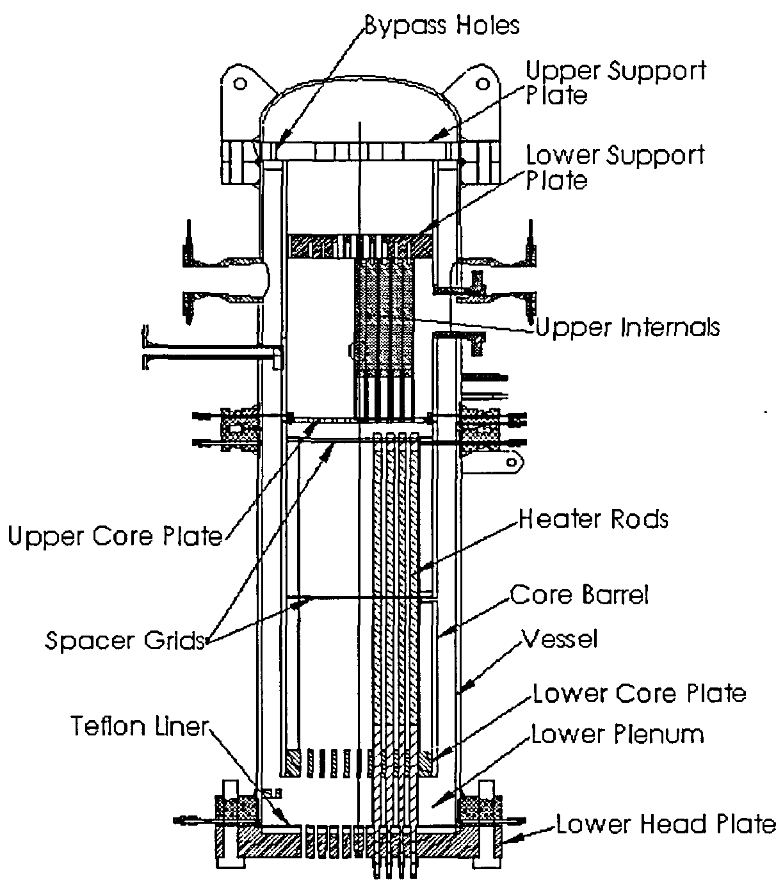

Figure 2-3 Reactor Cross-Section View

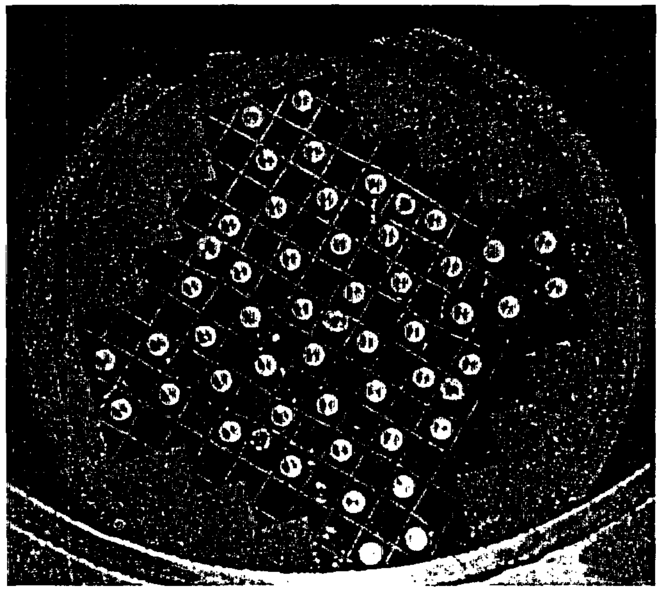

Figure 2-4 View of Reactor Core from Above

The heated water leaves the top of the core and flows upward through a [ ]^{a,b,c} thick upper core plate into the upper plenum. The upper plenum is bounded by the upper core plate and the lower support plate (see Figure 2-3). The upper core plate serves to support the upper plenum internals that simulate the control rod guide tubes and other upper plenum structure. The heated water leaves the upper plenum via the two, [ ]^{a,b,c} hot leg nozzles.

The volume above the upper support plate is the upper head region. It is connected to the upper plenum via 10 holes of [ ]^{a,b,c} diameter and a single [ ]^{a,b,c} diameter hole in the upper support plate with a total flow area of [ ]^{a,b,c}. The [ ]^{a,b,c} diameter hole in the center of the upper support plate allows a capacitance level probe to penetrate to just above the upper core plate. The capacitance probe provides a mixture level in the core region. It is also connected to the downcomer via ten [ ]^{a,b,c} diameter bypass holes located at the top of the downcomer. A list of the key components in the RPV is given in Table 2-1.

Table 2-1 Components in Reactor Pressure Vessel

a,b,c

Table 2-2 is a list of the T/Cs located in the RPV. The pressure instrumentation in the RPV (see LKL 911218, Rev. 3, Sheet 2 of 2) is listed in Table 2-3.

Table 2-2	Thermocouples in Reactor Pressure Vessel		
Tag Name	**Description**	**Tag Name**	**Description**
TF-101	CL-3/Reactor Flange @ Top	TF-163	Lower Rx Vessel Layer A-A @ 135 degrees
TF-102	CL-4/Reactor Flange @ Top	TF-164	Upper Rx Vessel Layer H-H @ 0 degrees
TF-103	CL-3/Reactor Flange @ Bottom	TF-165	Upper Rx Vessel Layer H-H @ 6.2 degrees
TF-104	CL-4/Reactor Flange @ Bottom	TF-166	Upper Rx Vessel Layer I-I @ 0 degrees
TF-105	CL-1/Reactor Flange @ Top	TF-167	Heater Rod B2-319 @ 40.13"
TF-106	CL-2/Reactor Flange @ Top	TF-168	Upper Rx Vessel Layer K-K @ 270 degrees
TF-107	CL-1/Reactor Flange @ Bottom	TF-169	Upper Rx Vessel Layer M-M @ 90 degrees
TF-108	CL-2/Reactor Flange @ Bottom	TF-170	Upper Rx Vessel Layer M-M @ 270 degrees
TF-113	DVI-1/Reactor Flange @ Top	TF-171	Top of Reactor Down to within 0.50" of Upper Support Plate
TF-114	DVI-2/Reactor Flange @ Bottom	TF-172	Lower Rx Vessel Layer AA-AA @ 0 degrees
TF-115	DVI-1/Reactor Flange @ Bottom	TF-173	Lower Rx Vessel Layer AA-AA @ 270 degrees
TF-116	DVI-2/Reactor Flange @ Top	TR-001-1	Core Thermocouple Rod D-001 @ 10.50"
TF-118	Lower Rx Vessel Layer Y-Y @ 30 degrees	TR-001-2	Core Thermocouple Rod D-001 @ 19.13"
TF-120	Top of Reactor @ 8.5" & 350 degrees	TR-001-3	Core Thermocouple Rod D-001 @ 25.13"
TF-126	Lower Rx Vessel Layer A-A @ 225 degrees	TR-001-4	Core Thermocouple Rod D-001 @ 31.13"
TF-127	Lower Rx Vessel Layer A-A @ 315 degrees	TR-001-5	Core Thermocouple Rod D-001 @ 37.13"
TF-128	Lower Rx Vessel Layer C-C @ 0 degrees	TR-001-6	Core Thermocouple Rod D-001 @ 43.13"
TF-129	Lower Rx Vessel Layer C-C @ 32 degrees	TR-303-1	Core Thermocouple Rod D-303 @ 10.51"
TF-130	Lower Rx Vessel Layer G-G @ 0 degrees	TR-303-2	Core Thermocouple Rod D-303 @ 19.13"
TF-131	Lower Rx Vessel Layer G-G @ 11.3 degrees	TR-303-3	Core Thermocouple Rod D-303 @ 25.13"
TF-132	Upper Rx Vessel Layer F-F @ 0 degrees	TR-303-4	Core Thermocouple Rod D-303 @ 31.13"
TF-133	Upper Rx Vessel Layer F-F @ 8 degrees	TR-303-5	Core Thermocouple Rod D-303 @ 37.13"
TF-134	Upper Rx Vessel Layer E-E @ 0 degrees	TR-303-6	Core Thermocouple Rod D-303 @ 43.13"
TF-135	Upper Rx Vessel Layer E-E @ 6.2 degrees	TR-308-1	Core Thermocouple Rod E-308 @ 22.13"
TF-140	HL-2/Reactor Flange @ Top	TR-308-2	Core Thermocouple Rod E-308 @ 34.13"
TF-141	HL-1/Reactor Flange @ Top	TR-308-3	Core Thermocouple Rod E-308 @ 46.13"

Table 2-2 Thermocouples in Reactor Pressure Vessel (cont.)			
Tag Name	**Description**	**Tag Name**	**Description**
TF-142	HL-2/Reactor Flange @ Bottom	TR-308-4	Core Thermocouple Rod D-001 @ 49.13"
TF-143	HL-1/Reactor Flange @ Bottom	TR-308-5	Core Thermocouple Rod D-001 @ 51.13"
TF-147	Upper Rx Vessel Layer I-I @ 180 degrees	TR-308-6	Core Thermocouple Rod D-303 @ 49.13"
TF-148	Upper Rx Vessel Layer I-I @ 188 degrees	TR-313-1	Core Thermocouple Rod D-313 @ 10.50"
TF-149	Upper Rx Vessel Layer H-H @ 180 degrees	TR-313-2	Core Thermocouple Rod D-313 @ 19.13"
TF-150	Upper Rx Vessel Layer H-H @ 186.2 degrees	TR-313-3	Core Thermocouple Rod D-313 @ 25.13"
TF-151	Upper Rx Vessel Layer E-E @ 186.2 degrees	TR-313-4	Core Thermocouple Rod D-313 @ 31.13"
TF-152	Upper Rx Vessel Layer E-E @ 180 degrees	TR-313-5	Core Thermocouple Rod D-313 @ 37.13"
TF-153	Upper Rx Vessel Layer F-F @ 180 degrees	TR-313-6	Core Thermocouple Rod D-313 @ 43.13"
TF-154	Upper Rx Vessel Layer F-F @ 188 degrees	TR-318-1	Core Thermocouple Rod F-318 @ 28.13"
TF-155	Lower Rx Vessel Layer G-G @ 180 degrees	TR-318-2	Core Thermocouple Rod F-318 @ 40.13"
TF-156	Lower Rx Vessel Layer G-G @ 191.3 degrees	TR-318-3	Core Thermocouple Rod F-318 @ 51.86"
TF-157	Lower Rx Vessel Layer C-C @ 212 degrees	TR-318-4	Core Thermocouple Rod D-303 @ 51.13"
TF-158	Lower Rx Vessel Layer C-C @ 180 degrees	TR-318-5	Core Thermocouple Rod D-313 @ 49.13"
TF-162	Lower Rx Vessel Layer A-A @ 45 degrees	TR-318-6	Core Thermocouple Rod D-313 @ 51.13"

Table 2-3	Pressure Instrumentation in Reactor Pressure Vessel
Tag Name	**Description**
DP-111	DP Across Upper Core Plate
DP-114	DP Across Upper Support Plate
DP-121	DVI-1/Cold Leg 1 Differential Pressure
DP-122	DP Between DVI-2 and CL-2
DP-123	DP Between DVI-1 and CL-3
DP-124	DP Between DVI-2 and CL-4
DP-125	HL-1 Entrance Losses
DP-126	HL-2 Entrance Losses
DP-128	HL-2 Entrance Losses
LDP-101	CL to Bypass Holes Uncompensated Water Level (270)
LDP-102	CL to Bypass Holes Water Uncompensated Level (180)
LDP-103	DVI to CL Uncompensated Water Level (270)
LDP-104	DVI to CL Uncompensated Water Level (180)
LDP-105	Upper Core Plate to DVI Uncompensated Water Level (270)
LDP-106	Bottom of Core to Lower Core Plate Uncompensated Water Level (180)
LDP-107	Bottom of Core to Lower Core Plate Uncompensated Water Level (270)
LDP-108	Bottom of Core to Lower Core Plate Uncompensated Water Level (0)
LDP-109	Lower Core Plate to Mid-Core Spacer Grid (0) Uncompensated Water Level
LDP-110	Mid-Core Spacer Grid to Upper-Core Spacer Grid (0) Uncompensated Water Level
LDP-112	Upper Core Plate to DVI Water Level (0) Uncompensated Water Level
LDP-113	DVI to Bottom of Upper Support Plate (0) Uncompensated Water Level
LDP-115	Upper Support Plate to Top of Reactor Uncompensated Water Level
LDP-116	Bottom of Reactor to Bottom of Bypass Holes (270) Uncompensated Water Level
LDP-117	Upper Core Spacer Grid to DVI Water Uncompensated Level (180)
LDP-118	Lower Core Plate to Upper Core Plate (270) Uncompensated Water Level
LDP-119	Lower Core Plate to Upper Core Support Grid (180) Uncompensated Water Level

Table 2-3	Pressure Instrumentation in Reactor Pressure Vessel (cont.)
Tag Name	**Description**
LDP-127	Reactor Wide Range Uncompensated Level
LDP-138	Upper Core Spacer Grid to Bottom of Upper Support Plate (180) Uncompensated Water Level
LDP-139	Top of Lower Core Plate to Upper Core Spacer Grid Uncompensated Level
LDP-140	Bottom of Reactor to Bottom of Flow Holes (180) Uncompensated Water Level
LDP-141	Rx Vessel Upper Core Plate Uncompensated Level
PT-101	CL-1 Pressure @ Reactor Flange
PT-102	CL-2 Pressure @ Reactor Flange
PT-103	CL-3 Pressure @ Reactor Flange
PT-104	CL-4 Pressure @ Reactor Flange
PT-107	Reactor Upper Head Pressure
PT-108	Bottom of Reactor Pressure
PT-109	DVI-1 Pressure @ Reactor Flange
PT-110	DVI-2 Pressure @ Reactor Flange
PT-111	Reactor Annular Pressure @ Flow Bypass Holes
PT-112	Reactor Annular Pressure @ Bottom of Reactor
PT-113	Reactor Pressure Below Mid-Core Spacer Grid

The locations of the fluid T/Cs in the downcomer of the RPV are shown in Figure 2-5, which is an unwrapped image of the downcomer region. The tag descriptions for each of the numbered T/Cs in Figure 2-5 are given in Table 2-4. The distribution of T/Cs in the downcomer can also be seen in reference drawing [OSU 400101, Rev. 0, Sheet 1 of 1].

a,b,c

Figure 2-5 Thermocouple Map of Downcomer

a,b,c

Table 2-4 Thermocouple Legend for Figure 2-5

Table 2-4 Thermocouple Legend for Figure 2-5 (cont.)

a,b,c

2.2 Pressurizer (PZR)

A fully functional PZR, with internal heaters and a relief valve system capable of controlling the RCS pressure, has been included. The PZR is connected to HL-2 through the PZR surge line. The diameter of the PZR is not constant along its entire length; the lower cylindrical portion is constructed from [ ]^{a,b,c} pipe, and the upper cylindrical portion is constructed from [ ]^{a,b,c} pipe (see Figure 2-6). The larger diameter top on the pressurizer was required for the APEX facility since there was not enough vertical space in the lab to accommodate the height of the PZR if the diameter remained constant (See Figure 2-7; note the notch in the beam made to accommodate the taller PZR). The larger upper portion of the PZR is above the normal PZR water level, so only steam is present in the upper portion. The total volume of the PZR is [ ]^{a,b,c}. The PZR in the APEX facility does not use a condensing spray for reduction of pressure; instead a vent is used to exhaust steam. A line from the first three stages of the ADS is connected to the top of the PZR for modeling the ADS system depressurization of the primary system.

The PZR heaters consists of four, [ ]^{a,b,c} diameter, [ ]^{a,b,c} heaters, which are approximately [ ]^{a,b,c} long with a [ ]^{a,b,c} heated length. A T/C is installed in the disk end (top) of each heater. The heaters are installed approximately [ ]^{a,b,c} into the PZR. The PZR also has a [ ]^{a,b,c} air-operated valve to allow remote draining of the PZR. See Table 2-5 for a list of some of the PZR components and Table 2-6 for a list of related instruments.

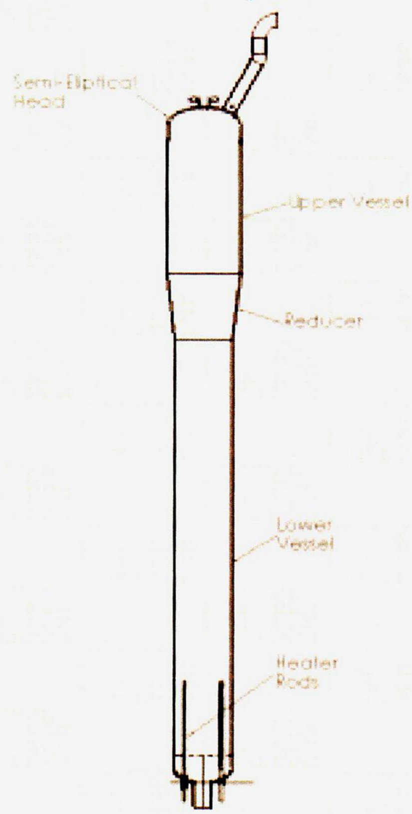

Figure 2-6 Illustration of Pressurizer Geometry

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Table 2-5 Components of Pressurizer

a,b,c

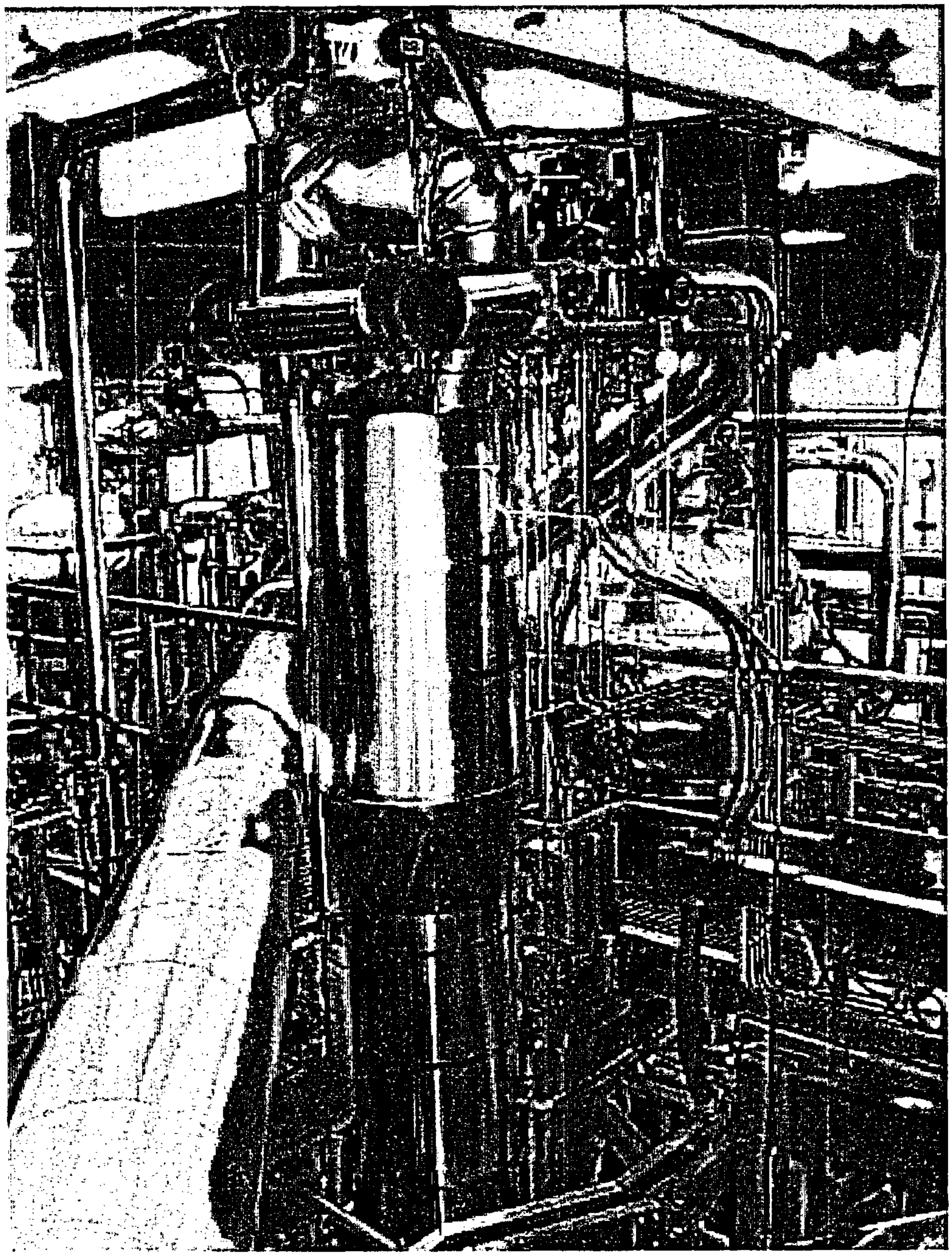

Figure 2-7 Photograph of Pressurizer in APEX Facility

Table 2-6 List of Pressurizer Instrument Names and Locations			
LDP, HPS, DP, KW, and PT Cells		Thermocouples	
Tag Name	**Description**	**Tag Name**	**Description**
DP-611	PZR Surge Line DP	TF-601	PZR Surge Line @ PZR Inlet
HPS-604-1	Lower PZR Surge Line Heat Transfer Coefficient	TF-602	ADS1-3 Common Line @ PZR
HPS-604-2	Lower PZR Surge Line Heater dT above fluid temperature	TF-603	PZR Surge Line @ HL-2
HPS-604-3	Lower PZR Surge Line Fluid temperature	TF-605	PZR Water Space Temperature
HPS-606-1	ADS1-3 Common Inlet Heat Transfer Coefficient	TF-608	PZR Fluid Temperature
HPS-606-2	ADS1-3 Common Inlet Heater dT above fluid temperature	TF-614	PZR Steam Vent Line Temperature
HPS-606-3	ADS1-3 Common Inlet Fluid temperature	TH-601	PZR Heater Rod #1
KW-601	PZR Heater Power	TH-602	PZR Heater Rod #2
LDP-601	PZR WR Uncompensated Water Level	TH-603	PZR Heater Rod #3
LDP-602	PZR Surge Line Uncompensated Water Level	TH-604	PZR Heater Rod #4
LDP-605	PZR Upper Surge Line Pipe Uncompensated Water Level		
LDP-606	PZR Surge Line Pipe Level @ PZR Inlet Uncompensated Water Level		
LDP-607	PZR Middle Surge Line Pipe Uncompensated Water Level		
LDP-608	PZR Lower Surge Line Pipe Uncompensated Water Level		
LDP-609	PZR Surge Line Pipe Uncompensated Water Level @ HL-2		
PT-602	PZR NR Pressure		
PT-603	PZR NR Pressure		
PT-604	PZR Pressure		

2.3 Steam Generators (SGs)

Two SGs, one on each loop, have been included in the APEX facility. Each SG is instrumented and has a tube and shell made to simulate a Westinghouse Delta-75 Steam Generator (see Figure 2-8). The SG lower channel head includes connections for two RCPs and a single HL. SG 2 contains a line from the PRHR HX located inside the IRWST. The T/Cs are attached to the outer surface and are embedded into the walls of selected SG tubes. Each SG contains 133 U-tubes with [ ]^{a,b,c} O.D., [ ]^{a,b,c}. See Figure 2-8, Figure 2-9, and Figure 2-10 for images of the SG. A summary of some of the SG components is given in Table 2-7.

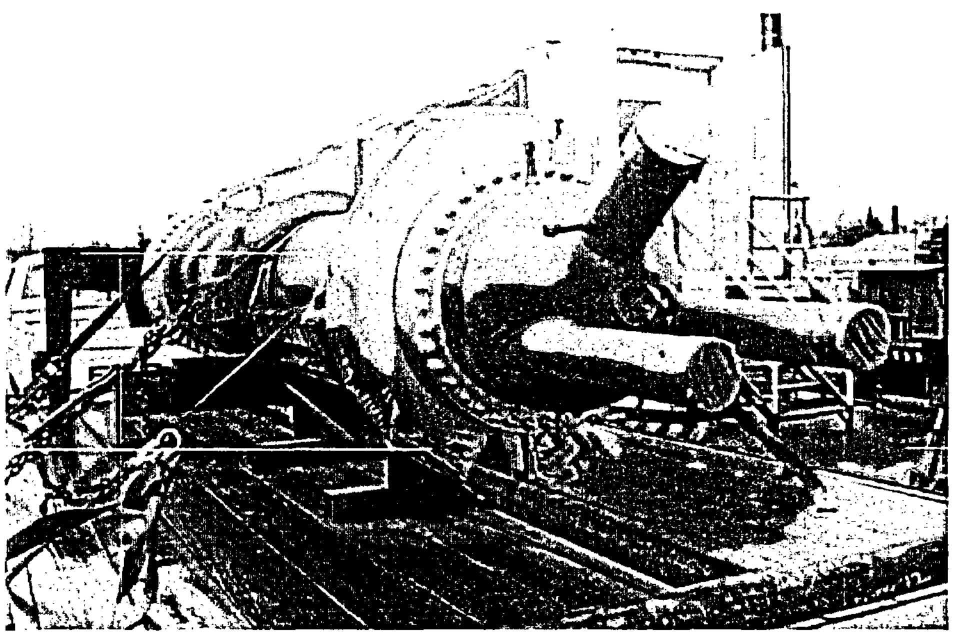

Figure 2-8 Steam Generator Being Delivered to APEX Facility

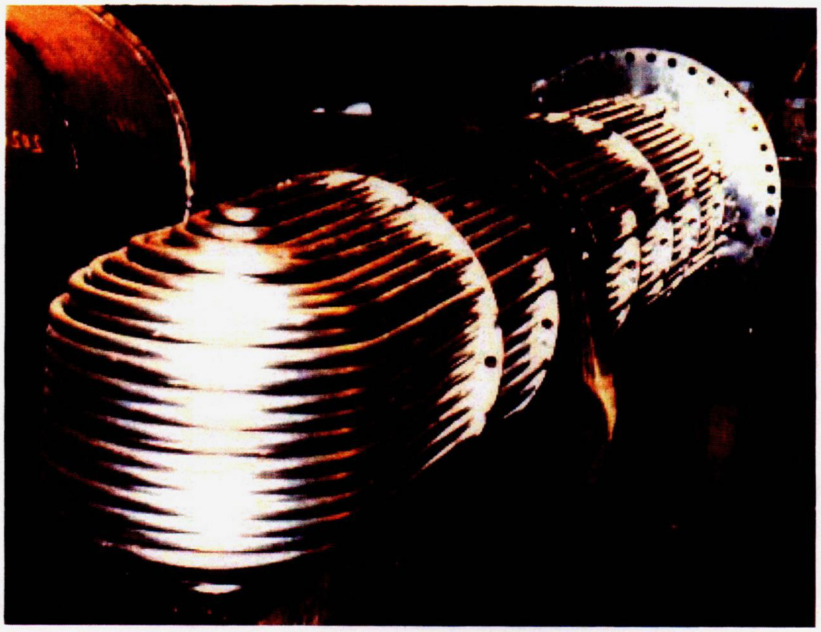

Figure 2-9 Steam Generator U-Tube Bundle

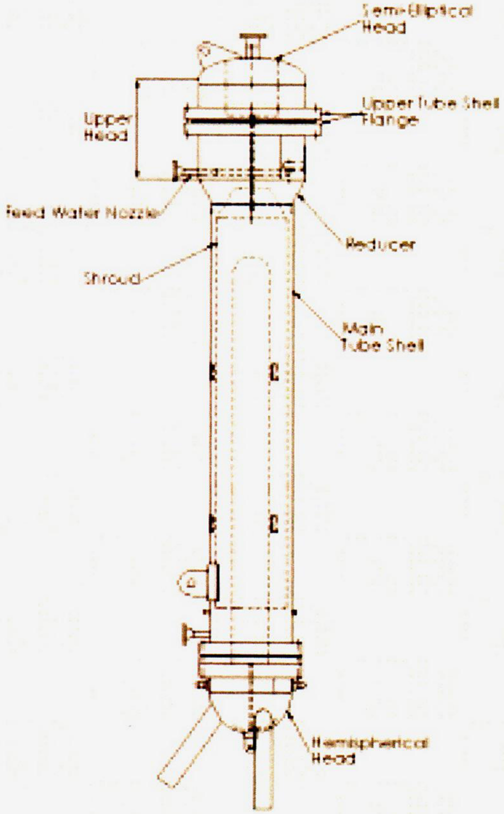

Figure 2-10 Steam Generator Components

C03

Table 2-7 Components of Steam Generators (Each)

a,b,c

A power-operated relief valve (PORV), and associated piping, is installed on both SGs and is connected to the exhaust header. The PORV connects to the top of each SG via a [ ]^{a,b,c} pipe. A [ ]^{a,b,c} air-operated ball valve provides remote actuation. A [ ]^{a,b,c} flow orifice is installed in each line to limit steam flow to approximately [ ]^{a,b,c} flow at [ ]^{a,b,c}. Each line includes a T/C, a pressure transmitter, and a Vortex flow meter. To provide flow measurement within the desired range, the PORV line is enlarged to [ ]^{a,b,c} and a [ ]^{a,b,c} Vortex flow meter is installed. The PORV line discharges into a common [ ]^{a,b,c} steam line, which is then routed into the steam exhaust stack. A list of the instruments associated with the secondary side of the SGs is given in Table 2-8, while the SGs' primary side instruments are listed in Table 2-9.

Table 2-8 List of Steam Generator Instrument Names and Locations (Secondary Side)			
LDP and PT Cells		Thermocouples	
Tag Name	Description	Tag Name	Description
LDP-301	SG-01 WR Uncompensated Water Level	TF-301	SG-01 Steam Temperature
LDP-302	SG-02 WR Uncompensated Water Level	TF-305	SG-01 Downcomer HL Side Temperature
LDP-303	SG-01 NR Uncompensated Water Level	TF-306	SG-02 Downcomer HL Side Temperature
LDP-304	SG-02 NR Uncompensated Water Level	TF-307	SG-01 Downcomer CL Side Temperature
PT-301	SG-01 Pressure	TF-308	SG-02 Downcomer CL Side Temperature
PT-302	SG-02 Pressure	TF-310	SG-02 Steam Temperature
		TF-311	SG-01 Feed Header Temperature
		TF-312	SG-02 Feed Header Temperature

Table 2-9 List of Steam Generator Instrument Names and Locations (Primary Side)			
LDP, DP, and PT Cells		Thermocouples	
Tag Name	Description	Tag Name	Description
DP-211	SG-1 Short Tube Entrance Losses	TF-207	SG-01 Short Tube @ Middle Outlet Side Temperature
DP-212	SG-2 Long Tube Exit Losses	TF-208	SG-02 Short Tube @ Middle Outlet Side Temperature
DP-213	SG-1 Long Tube Exit Losses	TF-209	SG-01 Short Tube @ Middle Inlet Side Temperature
DP-214	SG-2 Long Tube Entrance Losses	TF-210	SG-02 Short Tube @ Middle Inlet Side Temperature
LDP-207	SG-01 to HL-1 Elbow Plenum Uncompensated Water Level	TF-211	SG-01 Long Tube @ Middle Outlet Temperature
LDP-208	SG-02 to HL-2 Elbow Plenum Uncompensated Water Level	TF-212	SG-02 Long Tube @ Middle Outlet Temperature
LDP-209	SG-01 HL Plenum Uncompensated Water Level	TF-213	SG-01 Long Tube @ Middle Inlet Temperature
LDP-210	SG-02 CL-4 Plenum Uncompensated Water Level	TF-214	SG-02 Long Tube @ Middle Inlet Temperature

Table 2-9 List of Steam Generator Instrument Names and Locations (Primary Side) (cont.)			
LDP, DP, and PT Cells		Thermocouples	
Tag Name	Description	Tag Name	Description
LDP-211	SG-01 CL-3 Plenum Uncompensated Water Level	TF-215	SG-01 Short Tube @ Top Temperature
LDP-212	SG-02 CL-2 Plenum Uncompensated Water Level	TF-216	SG-02 Short Tube @ Top Temperature
LDP-213	SG-01 CL-1 Plenum Uncompensated Water Level	TF-217	SG-01 Long Tube @ Top Temperature
LDP-214	SG-02 HL Plenum Uncompensated Water Level	TF-218	SG-02 Long Tube @ Top Temperature
LDP-215	SG-01 Long Tube HL Uncompensated Water Level	TW-201	SG-01 Short Tube Bottom Outlet
LDP-216	SG-02 Short Tube HL Uncompensated Water Level	TW-202	SG-02 Short Tube Bottom Outlet
LDP-217	SG-01 Short Tube HL Uncompensated Water Level	TW-203	SG-01 Short Tube Bottom Inlet
LDP-218	SG-02 Long Tube HL Uncompensated Water Level	TW-204	SG-02 Short Tube Bottom Inlet
LDP-219	SG-01 Long Tube CL Uncompensated Water Level	TW-205	SG-01 Long Tube Bottom Outlet
LDP-220	SG-02 Short Tube CL Uncompensated Water Level	TW-206	SG-02 Long Tube Bottom Outlet
LDP-221	SG-01 Short Tube CL Uncompensated Water Level	TW-208	SG-02 Long Tube Bottom Inlet
LDP-222	SG-02 Long Tube CL Uncompensated Water Level	TW-209	SG-01 Short Tube Top Outlet
PT-201	SG-01 Long Tube Pressure (Top)	TW-210	SG-02 Short Tube Top Outlet
PT-204	SG-02 Long Tube Pressure (Top)		

The detailed geometry of the SG is found is the reference drawings [20175-D1, Rev. B; 20175-D2, Rev. B; and 20175-D3, Rev. A].

2.4 Reactor Coolant Pump (RCP)

Four variable speed RCPs have been included as part of the RCS. The RCPs simulate the AP1000 canned motor pumps and are attached to the lower channel head of each SG. Each pump outlet is connected to a single CL. The pumps are fabricated from SS 304 and can be programmed to simulate RCP coastdown. Each RCP has a normal operational flow rate capacity of [ ][a,b,c] at [ ][a,b,c]. Figure 2-11 shows two RCPs mounted on SG-02, while Figure 2-12 shows the pump head curve of the RCPs. See Table 2-10 for a list of the instrumentation related to the RCPs.

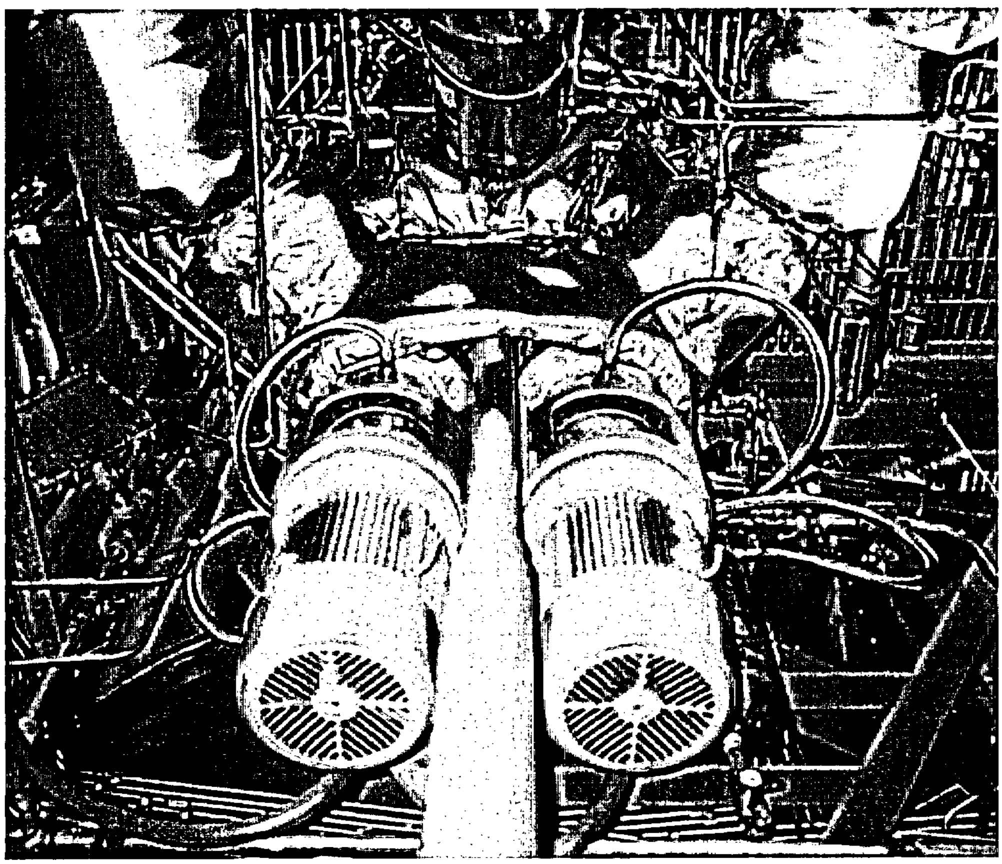

Figure 2-11 Image of Two Reactor Coolant Pumps from Bottom

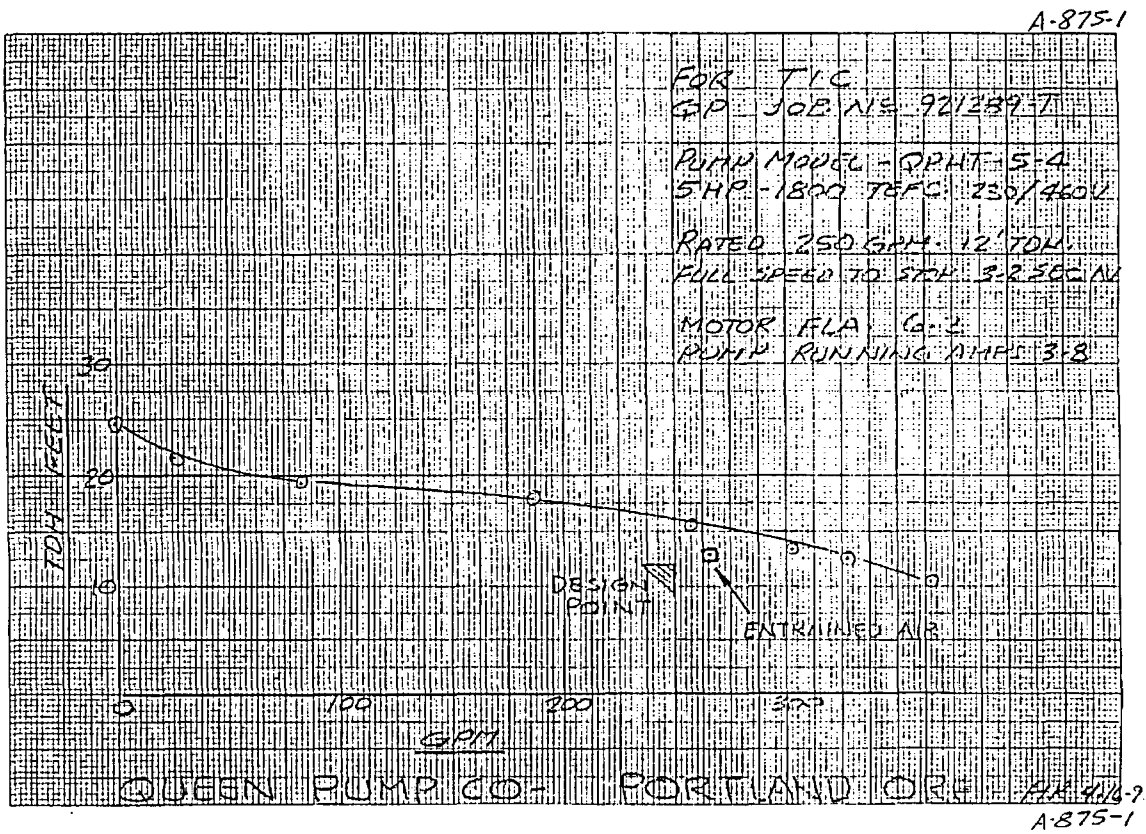

Figure 2-12 Reactor Coolant Pump Head Curve

Table 2-10 List of Reactor Coolant Pump Instrument Names and Locations			
Differential Pressure Cells		**Thermocouples**	
Tag Name	**Description**	**Tag Name**	**Description**
DP-202	RCP-2 DP	TF-201	CL-1 @ RCP-1 Inlet Temperature
DP-203	RCP-1 DP	TF-202	CL-2 @ RCP-2 Inlet Temperature
DP-205	RCP-3 DP	TF-203	CL-3 @ RCP-3 Inlet Temperature
DP-206	RCP-4 DP	TF-204	CL-4 @ RCP-4 Inlet Temperature

The detailed geometry of the RCP is given in the reference drawing [783-P01, 783-P02].

2.5 Primary Loop Piping

The primary loop piping models two primary loops, each consisting of a single HL and two CLs. Figure 2-8 shows the PZR side of the RCS.

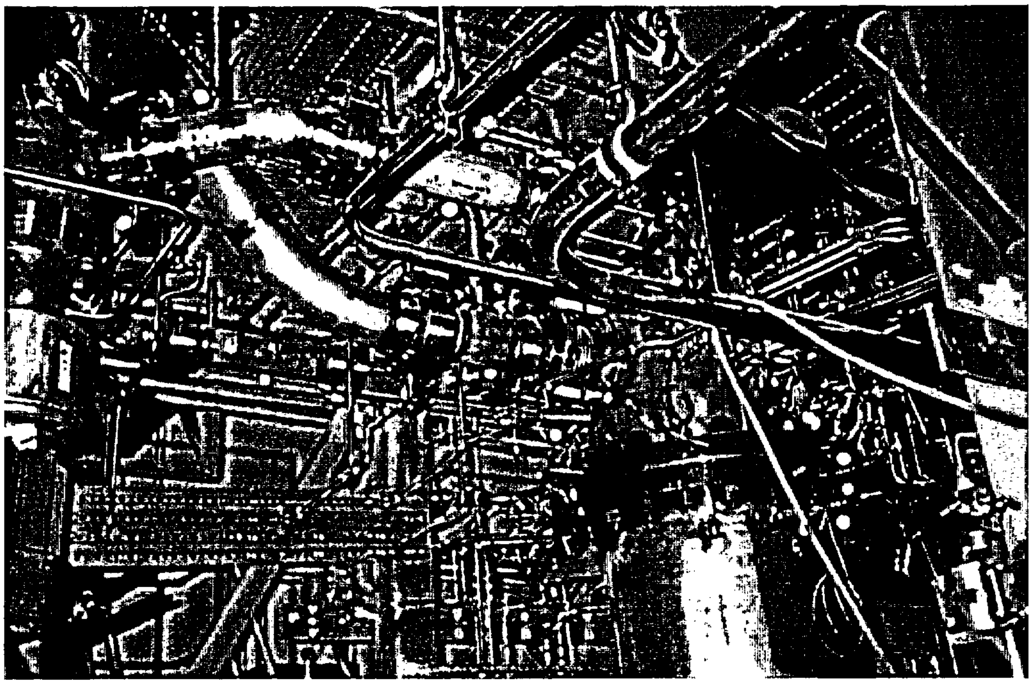

Figure 2-13 Primary Loop Piping in Reactor Coolant System

Break spool pieces are installed on the HLs, CLs, the DVI lines, and the CMT pressure balance line to simulate several pipe break scenarios. The primary loop breaks that the APEX facility is able to perform includes:

- Top break on CL-3
- Bottom break on CL-3
- Bottom break on CL-4
- Bottom break on HL-2
- Single-ended DVI break
- Single-ended CMT balance line break
- Double-ended DVI break
- Double-ended CMT balance line break

Each of the primary loop breaks is initiated by pneumatic valves connected to the aforementioned locations. The break flow passes through an orifice plate, whose purpose is to set the size of the break, and may be changed out at anytime to simulate different break flow areas. The discharge from the break vents proceeds to the Break and ADS Measurement System (BAMS) to separate and measure the liquid and vapor components of the break flow rate.

2.5.1 Hot Legs (HLs)

In the primary side, each loop consists of a single [ ]a,b,c, which in turn, feeds the inverted U-tube SG mounted vertically on the bottom of each SG channel head. The HLs have connections for the fourth-stage ADS (ADS-4). Refer to Table 2-11 for a list of instruments pertaining to the HL.

Table 2-11 List of Hot Leg Instrument Names and Locations

Tag Name	Description
DP-209	HL-2 DP
DP-210	HL-2 DP
DP-216	HL Break DP
DP-217	HL-1 to CL1 DP @ SG1
DP-218	HL-2 to CL2 DP @ SG2
DP-219	HL-1 to CL3 DP @ SG1
DP-220	HL-2 to CL4 DP @ SG2
DP-221	HL-1 to CL1 DP @ RX
DP-222	HL-2 to CL2 DP @ RX
DP-223	HL-1 to CL3 DP @ RX
DP-224	HL-2 to CL4 DP @ RX
HPS-205-1	HL-1 Heat Transfer Coefficient
HPS-205-2	HL-1 Heater dT above fluid temperature
HPS-205-3	HL-1 Fluid temperature
HPS-206-1	HL-2 Heat Transfer Coefficient
HPS-206-2	HL-2 Heater dT above fluid temperature
HPS-206-3	HL-2 Fluid Temperature
LDP-205	HL-1 Uncompensated Water Level
LDP-206	HL-2 Uncompensated Water Level
LDP-207	SG-01 to HL-1 Elbow Plenum Uncompensated Water Level
LDP-208	SG-02 to HL-2 Elbow Plenum Uncompensated Water Level
LDP-209	SG-01 HL Plenum Uncompensated Water Level
LDP-214	SG-02 HL Plenum Uncompensated Water Level
PT-202	HL-2 Pressure @ SG-02 Flange
PT-205	HL-1 Pressure @ SG-01 Flange
PT-206	HL Break Pressure @ Break Valve

2.5.2 Cold Legs (CLs)

In the primary side, each loop consists of two, 3.5 in. sch. 40 CLs, which in turn, feed the reactor core. The CL interconnects the reactor core and one of the two RCPs attached at the bottom of the SG. CL-1 and CL-3 have connections for the CMT pressure balance lines connected to the tops of the CMT-2 and CMT-1, respectively. See Table 2-12 for a list of CL instrumentation.

Table 2-12 List of Cold Leg Instrument Names and Locations

DP, LDP, HPS, FMM, and PT Cells		Thermocouples	
Tag Name	**Description**	**Tag Name**	**Description**
DP-201	CL-1 DP	TF-201	CL-1 @ RCP-1 Inlet Temperature
DP-204	CL-2 DP	TF-202	CL-2 @ RCP-2 Inlet Temperature
DP-207	CL-3 DP	TF-203	CL-3 @ RCP-3 Inlet Temperature
DP-208	CL-4 DP	TF-204	CL-4 @ RCP-4 Inlet Temperature
DP-217	HL-1 to CL-1 DP @ SG1	TF-221	CL3 T/C Rod @3.25 in. (8.26 cm)
DP-218	HL-2 to CL-2 DP @ SG2	TF-222	CL-4 T/C Rod @ 3.25 in. (8.26 cm)
DP-219	HL-1 to CL-3 DP @ SG1	TF-223	CL3 T/C Rod @ 2.50 in. (6.35 cm)
DP-220	HL-2 to CL-4 DP @ SG2	TF-224	CL-4 T/C Rod @ 2.50 in. (6.35 cm)
DP-221	HL-1 to CL-1 DP @ RX	TF-225	CL-3 T/C Rod @ 1.75 in. (4.45 cm)
DP-222	HL-2 to CL-2 DP @ RX	TF-226	CL-4 T/C Rod @ 1.75 in. (4.45 cm)
DP-223	HL-1 to CL-3 DP @ RX	TF-227	CL-3 T/C Rod @ 1.25 in. (3.18 cm)
DP-224	HL-2 to CL-4 DP @ RX	TF-228	CL-4 T/C Rod @ 1.25 in. (3.18 cm)
FMM-201	CL-1 Loop Flow	TF-229	CL-3 T/C Rod @ 0.75 in. (1.91 cm)
FMM-202	CL-2 Loop Flow	TF-230	CL-4 T/C Rod @ 0.75 in. (1.91 cm)
FMM-203	CL-3 Loop Flow	TF-231	CL3 T/C Rod @ 0.25 in. (0.64 cm)
FMM-204	CL-4 Loop Flow	TF-232	CL-4 T/C Rod @ 0.25 in. (0.64 cm)
HPS-201-1	CL-1 Heat Transfer Coefficient	TF-251-1	Cold Leg 1 Loop Seal Upper Temperature
HPS-201-2	CL-1 Heater dT Above Fluid Temperature	TF-251-2	Cold Leg 1 Loop Seal Middle Temperature
HPS-201-3	CL-1 Fluid Temperature	TF-251-3	Cold Leg 1 Loop Seal Lower Temperature
HPS-202-1	CL-2 Heat Transfer Coefficient	TF-252-1	Cold Leg 2 Loop Seal Upper Temperature
HPS-202-2	CL-2 Heater dT Above Fluid Temperature	TF-252-2	Cold Leg 2 Loop Seal Middle Temperature
HPS-202-3	CL-2 Fluid Temperature	TF-252-3	Cold Leg 2 Loop Seal Lower Temperature
HPS-203-1	CL-3 Heat Transfer Coefficient	TF-253-1	Cold Leg 3 Loop Seal Upper Temperature
HPS-203-2	CL-3 Heater dT Above Fluid Temperature	TF-253-2	Cold Leg 3 Loop Seal Middle Temperature

Table 2-12 List of Cold Leg Instrument Names and Locations (cont.)			
DP, LDP, HPS, FMM, and PT Cells		Thermocouples	
Tag Name	**Description**	**Tag Name**	**Description**
HPS-203-3	CL-3 Fluid Temperature	TF-253-3	Cold Leg 3 Loop Seal Lower Temperature
HPS-204-1	CL-4 Heat Transfer Coefficient	TF-254-1	Cold Leg 4 Loop Seal Upper Temperature
HPS-204-2	CL-4 Heater dT Above Fluid Temperature	TF-254-2	Cold Leg 4 Loop Seal Middle Temperature
HPS-204-3	CL-4 Fluid Temperature	TF-254-3	Cold Leg 4 Loop Seal Lower Temperature
LDP-201	CL-1 Water Uncompensated Level	TF-255	Cold Leg 1 Safety Injection Nozzle Temperature
LDP-202	CL-2 Water Uncompensated Level	TF-256	Cold Leg 2 Safety Injection Nozzle Temperature
LDP-203	CL-3 Uncompensated Water Level	TF-257	Cold Leg 3 Safety Injection Nozzle Temperature
LDP-204	CL-4 Uncompensated Water Level	TF-258	Cold Leg 4 Safety Injection Nozzle Temperature
LDP-210	SG-02 CL-4 Plenum Uncompensated Water Level		
LDP-211	SG-01 CL-3 Plenum Uncompensated Water Level		
LDP-212	SG-02 CL-2 Plenum Uncompensated Water Level		
LDP-213	SG-01 CL-1 Plenum Uncompensated Water Level		
LDP-219	SG-01 Long Tube CL Uncompensated Water Level		
LDP-220	SG-02 Short Tube CL Uncompensated Water Level		
LDP-221	SG-01 Short Tube CL Uncompensated Water Level		
LDP-222	SG-02 Long Tube CL Uncompensated Water Level		
PT-203	CL Break Pressure @ Break Valve		

2.5.3 Pressurizer Surge Line

The PZR surge line connects the bottom of the PZR to the top of HL-2, near the SG end of the HL. The surge line enables continuous pressure adjustments between the RCS and the PZR. The PZR surge line is made of [ ]^{a,b,c} with an overall length of [ ]^{a,b,c}. The PRZ surge line spirals up from the HL to the PZR so that its geometry properly matches that of AP1000 (see Figure 2-14).

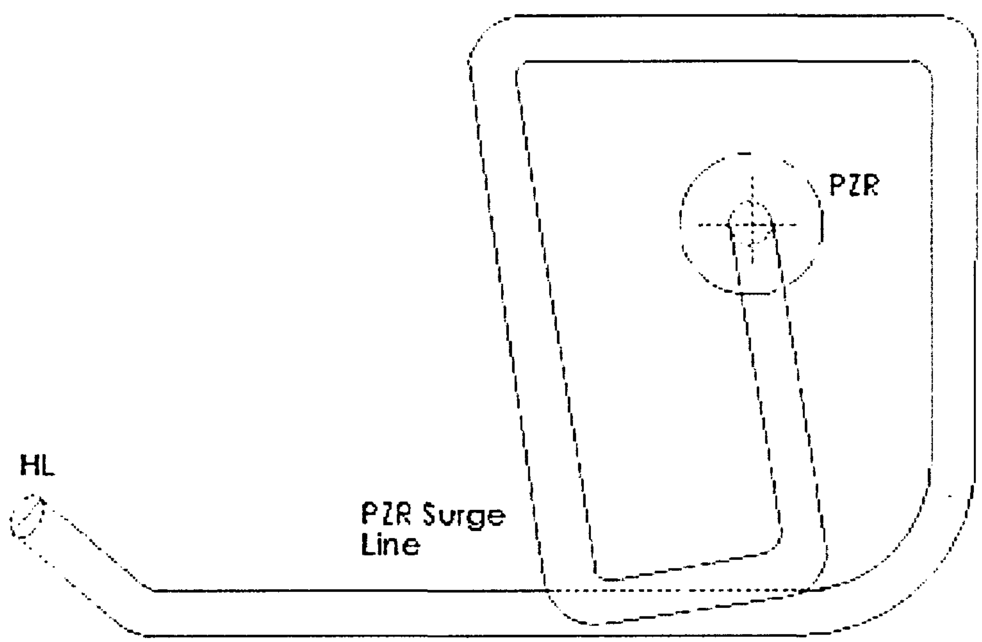

Figure 2-14 Pressurizer Surge Line Geometry

3.0 PASSIVE SAFETY SYSTEMS

3.1 Automatic Depressurization System (ADS) 1-4

The ADS 1-3 valves in the APEX facility model two trains in the AP1000. Each valve is located after a flow nozzle (see LKL 920202) that models the scaled choked flow area of the AP-1000. The ADS 1-3 valve train discharges to the ADS 1-3 separator where the two phase flow is separated and measured. All portions of the flow are re-combined before dumping into the ADS 1-3 sparger.

The ADS 1-3 valves exit at the top of the PZR through a single section of [ ]^{a,b,c} pipe. The [ ]^{a,b,c} pipe then splits in three and is reduced to [ ]^{a,b,c} previous to the ADS 2 and ADS 3 flow nozzles, and to [ ]^{a,b,c} previous to the ADS 1 flow nozzle. After the valves, the piping is recombined into a common pipe of [ ]^{a,b,c}, which is connected to the ADS 1-3 separator. The fluid is separated into the steam and liquid components inside the ADS 1-3 moisture separator. The steam flow and liquid flow are measured and then re-combined and dumped though a sparger into the IRWST. The sparger consists of four separate legs with a total of [ ]^{a,b,c} diameter holes (see Figure 3-1). The ADS 1 valve is either opened on "S"-signal, "S"-signal plus a time delay, or on CMT low level depending on the logic selected. ADS 2 and 3 valves open based on a time delay after actuation of ADS 1. Refer to sheets 1 through 4 of drawing ADS 1-3 of the AP-1000 as built drawings for a complete description of the piping and elevations of the ADS 1-3 system.

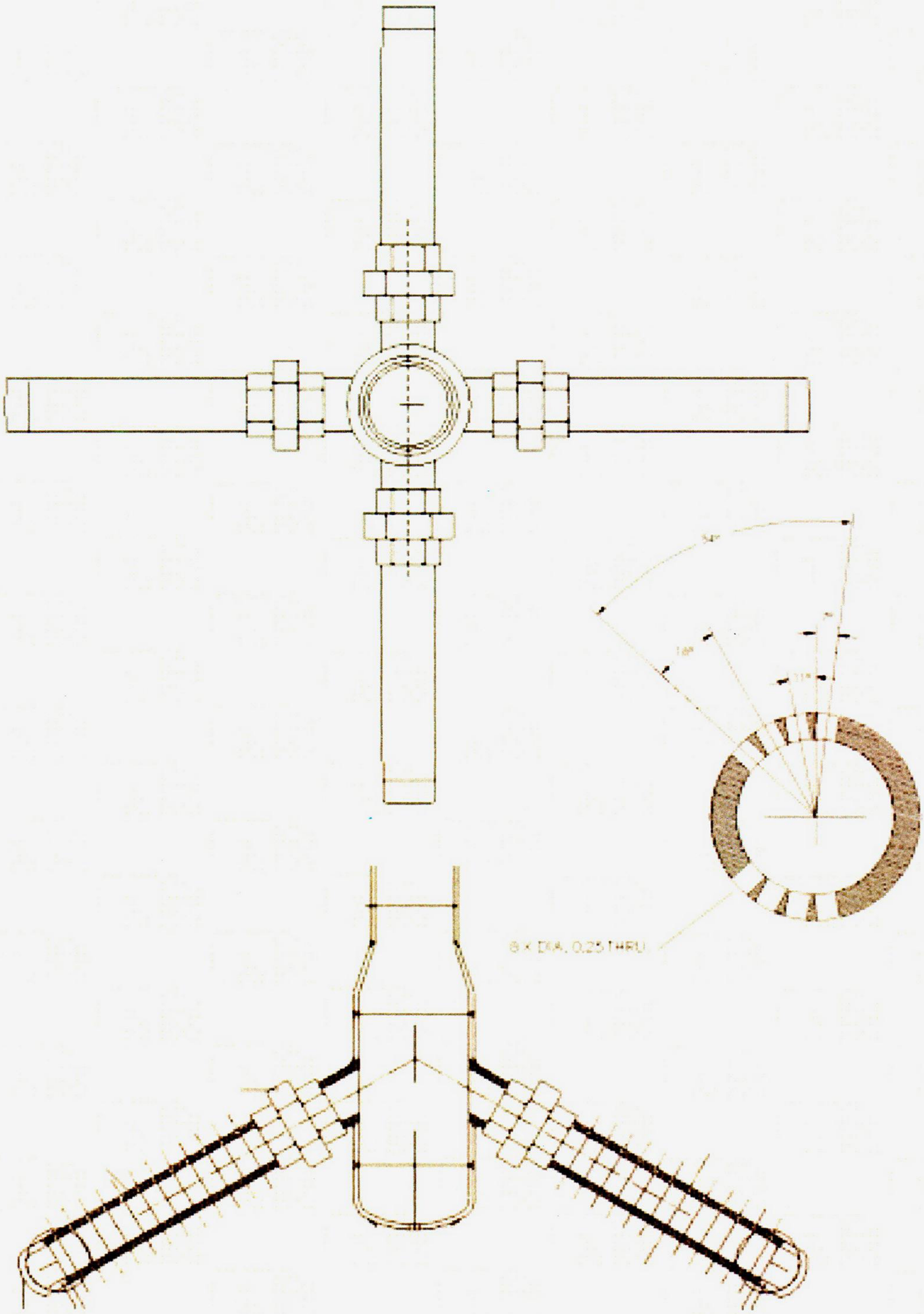

Figure 3-1 Illustration of Automatic Depressurization System 1-3 Sparger

An image of the ADS 1-3 sparger installed within the IRWST is shown in Figure 3-2. Refer to Table 3-1 for a list of instrumentation pertaining to the ADS 1-4 system.

C04

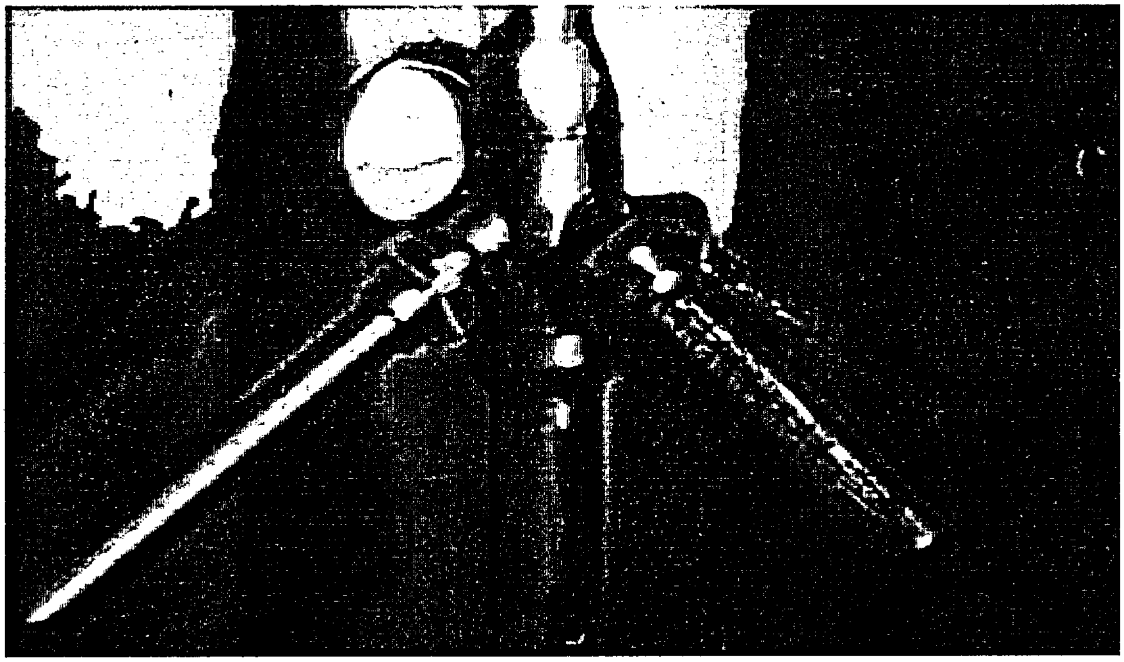

Figure 3-2 Photograph of Installed Sparger

Table 3-1 List of Automatic Depressurization System 1-4 Instrument Names and Locations			
LDP, FDP, HPS, FMM, and PT Cells		Thermocouples	
Tag Name	**Description**	**Tag Name**	**Description**
FDP-604	ADS-2 Flow Differential Pressure	TF-602	ADS1-3 Common Line @ PZR Temperature
FDP-605	ADS-1 Flow Differential Pressure	TF-609	ADS4-1 Discharge Temperature
FDP-606	ADS-3 Flow Differential Pressure	TF-610	ADS4-2 Discharge Temperature
FMM-601	ADS1-3 Loop Seal Flow	TF-615	ADS1-3 Common Line From PZR Temperature
FMM-602	ADS4-2 Loop Seal Flow	TF-616	ADS1-3 Separator Loop Seal Temperature
FMM-603	ADS4-1 Loop Seal Flow	TF-617	ADS1-3 Separator Steam Outlet Temperature
LDP-603	ADS-4A Vertical Exit Line Uncompensated Water Level	TF-618	ADS4-2 Loop Seal Temperature
LDP-604	ADS-4B Vertical Exit Line Uncompensated Water Level	TF-619	ADS4-1 Loop Seal Temperature

Table 3-1 List of Automatic Depressurization System 1-4 Instrument Names and Locations (cont.)			
LDP, FDP, HPS, FMM, and PT Cells		Thermocouples	
Tag Name	**Description**	**Tag Name**	**Description**
LDP-610	ADS1-3 Separator Uncompensated Water Level	TF-620	ADS4-2 Inlet From HL-2 Temperature
LDP-611	ADS4-1 Separator Uncompensated Water Level	TF-621	ADS4-1 Inlet From HL-1 Temperature
LDP-612	ADS4-2 Separator Uncompensated Water Level	TF-622	ADS4-2 Separator Steam Outlet Temperature
PT-605	ADS1-3 Separator Pressure	TF-623	ADS4-1 Separator Steam Outlet Temperature
PT-606	IRWST Sparger Line Pressure	TW-601	ADS1-3 Separator Wall Temperature
PT-610	ADS4-2 Separator Pressure	TW-602	ADS4-2 Separator Wall Temperature
PT-611	ADS4-1 Separator Pressure	TW-603	ADS4-1 Separator Wall Temperature
HPS-606-1	ADS1-3 Common Inlet Heat Transfer Coefficient		
HPS-606-2	ADS1-3 Common Inlet Heater dT Above Fluid Temperature		
HPS-606-3	ADS1-3 Common Inlet Fluid Temperature		

Two ADS 4 valves are connected to the top of HL-1 and HL-2 respectively. Both ADS 4 lines are similar with the exception that ADS 4-2 (PZR side) provides a tee connection for the PRHR HX system. Both ADS 4 lines are [ ]^{a,b,c} and include a venturi to valve flow area and line resistance. The flow from ADS 4 is directed to a moisture separator, where the steam and liquid flows are separated and measured individually. The steam flow is routed through a [ ]^{a,b,c} or [ ]^{a,b,c} line depending on the expected flow rate and is then vented from the facility. The liquid flow is directed through a loop seal and into the primary sump. Refer to pages 1 and 2 of drawing ADS 4 and 787-BAM-4, for a complete description of the piping and elevation of the ADS 4 system.

3.2 In-Containment Refueling Water Storage Tank (IRWST)

The APEX IRWST is constructed of SS 304 plate and has an inner diameter of [ ]^{a,b,c} and a wall thickness of [ ]^{a,b,c}. The working volume of liquid is [ ]^{a,b,c} at a level of [ ]^{b,c} and a liquid surface area of [ ]^{a,b,c}.

The IRWST has four major connections: the ADS 1-3 sparger, DVI 1 and 2, primary sump, and the PRHR connections. A summary of the components associated with the IRWST is given in Table 3-2.

Table 3-2 IRWST Components

a,b,c

A list of the instrumentation associated with the IRWST is given in Table 3-3 and Table 3-4. Table 3-3 contains a list the pressure, weight, and flow rate instruments for the IRWST, while the temperature measurement instrumentation is given in Table 3-4. The temperature of the fluid in the IRWST is measured at several heights to determine level height and stratification.

Table 3-3 List of IRWST LDP, LCT, FMM, DP, and PT Cells and Locations

Identifier	Description
DP-701	IRWST-1 Injection Differential Pressure
DP-702	IRWST-2 Injection Differential Pressure
FMM-701	IRWST-1 Injection Flow
FMM-702	IRWST-2 Injection Flow
FMM-703	IRWST Overflow
LDP-701	IRWST Uncompensated Water Level
PT-701	IRWST Pressure
LCT-701	IRWST Weight

Table 3-4	List of IRWST Thermocouples and Location		
Tag Name	**Description**	**Tag Name**	**Description**
TF-701	IRWST/PRHR T/C Rod @ Bottom Temperature	TF-713	IRWST Discharge to DVI-01 @ IRWST Temperature
TF-702	IRWST/PRHR T/C Rod @ 7.98 in. (20.27 cm)	TF-714	IRWST Discharge to DVI-02 @ IRWST Temperature
TF-703	IRWST/PRHR T/C Rod @ 15.97 in. (40.56 cm)	TF-715	IRWST Sparger T/C Rod @ 8.97 in. (22.78 cm)
TF-704	IRWST/PRHR T/C Rod @ 25.85 in. (65.67 cm)	TF-716	IRWST Sparger Nozzle Temperature
TF-705	IRWST/PRHR T/C Rod @ 35.73 in. (90.75 cm)	TF-717	IRWST Sparger T/C Rod @ 66.34 in. (168.50 cm)
TF-706	IRWST/PRHR T/C Rod @ 45.61 in. (115.85 cm)	TF-718	IRWST Sparger T/C Rod @ 98.45 in. (250.06 cm)
TF-707	IRWST/PRHR T/C Rod @ 55.49 in. (140.94 cm)	TF-719	IRWST Sparger Outlet Temperature
TF-708	IRWST/PRHR T/C Rod @ 65.36 in. (166.01 cm)	TF-720	IRWST/DVI-2 Injection Line Temperature
TF-709	IRWST/PRHR T/C Rod @ 75.24 in. (191.11 cm)	TF-721	IRWST/DVI-1 Injection Line Temperature
TF-710	IRWST/PRHR T/C Rod @ 86.36 in. (219.35 cm)	TF-722	IRWST Steam Exhaust Line Temperature
TF-711	IRWST/PRHR T/C Rod @ 97.47 in. (247.57 cm)	TF-723	IRWST/Primary Sump Overflow Temperature
TF-712	IRWST/PRHR T/C Rod @ 108.59 in. (275.82 cm)		

The two IRWST injection lines that connect into each DVI line starts at the bottom of the IRWST with [ ][a,b,c] O.D., [ ][a,b,c] I.D. SS 304 tubing, which in turn, connects to the [ ][a,b,c] SS 304 pipe connected to the DVI line. The IRWST injection lines are similar with the exception that IRWST 1 provides a connection to the Normal Residual Heat Removal System (RNS) pump suction. The IRWST injection line resistance is fine tuned by an orifice plate installed in each line. The IRWST isolation valves (RCS-711/712) are opened on decreasing RCS pressure [ ][a,b,c]. Refer to the drawings IRW 1 and IRW 2 of the As Built drawing set for a complete description of the piping and elevation of the connection between the IRWST to DVI. See Figure 3-3 for an image of the IRWST.

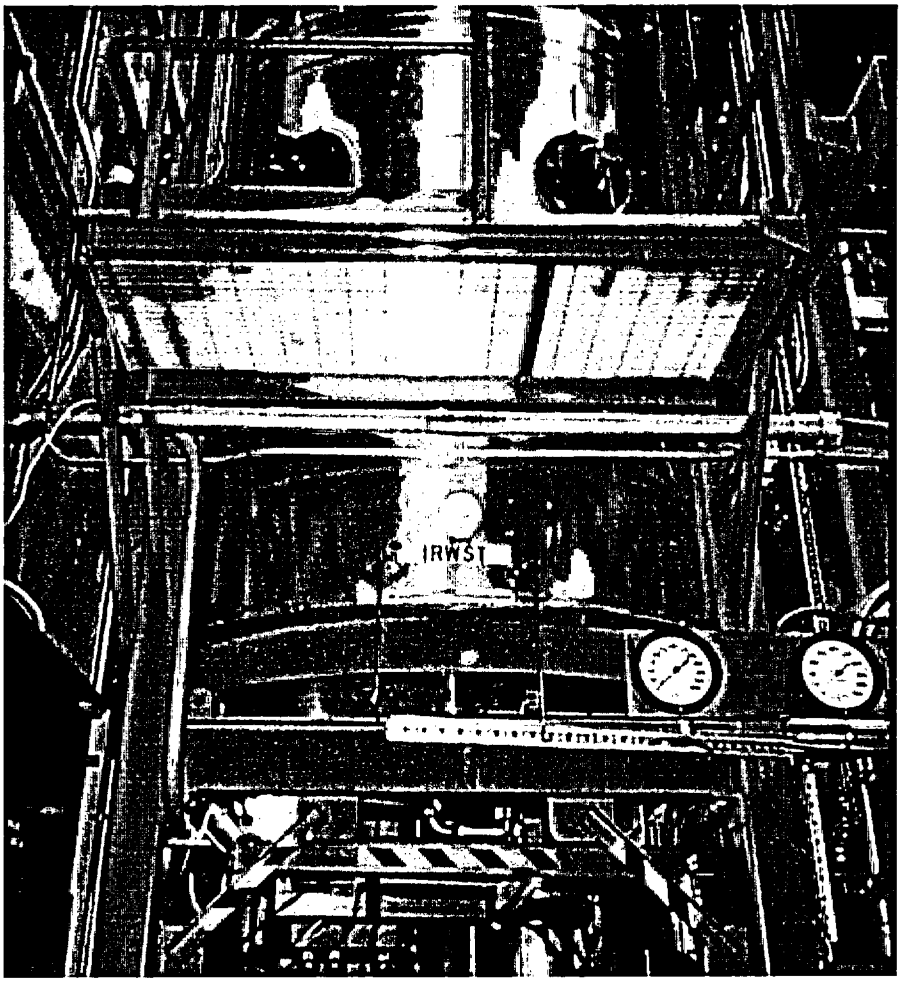

Figure 3-3 Photograph of IRWST

3.3 Core Makeup Tanks (CMT)

The CMTs are constructed of SS 304 and have an inside diameter of [ ]^{a,b,c}, an internal height of [ ]^{a,b,c}, and a liquid volume of about [ ]^{a,b,c}. Each CMT is connected to a CL and to a DVI line by [ ]^{a,b,c} O.D., [ ]^{a,b,c} I.D. SS 304 tubing. The CMT injection line isolation valves (RCS-529/530) open on "S"-signal for the station blackout subroutine or "S"-signal plus a [ ]^{a,b,c} delay for all other routines. The line resistance of the CMT injection lines is fine tuned through the use of an orifice. The isolation valves in the CMT balance line (RCS-535/536) have no automatic control and remain open during facility testing. Refer to CT 1, CT 2, CMT 1, and CMT 2 of the As Built drawing set for a complete description of the piping and elevation of the connection between the CMTs and the DVI/CL. See Figure 3-4 for an image of one of the CMTs. A summary of the components of the CMTs is given in Table 3-5.

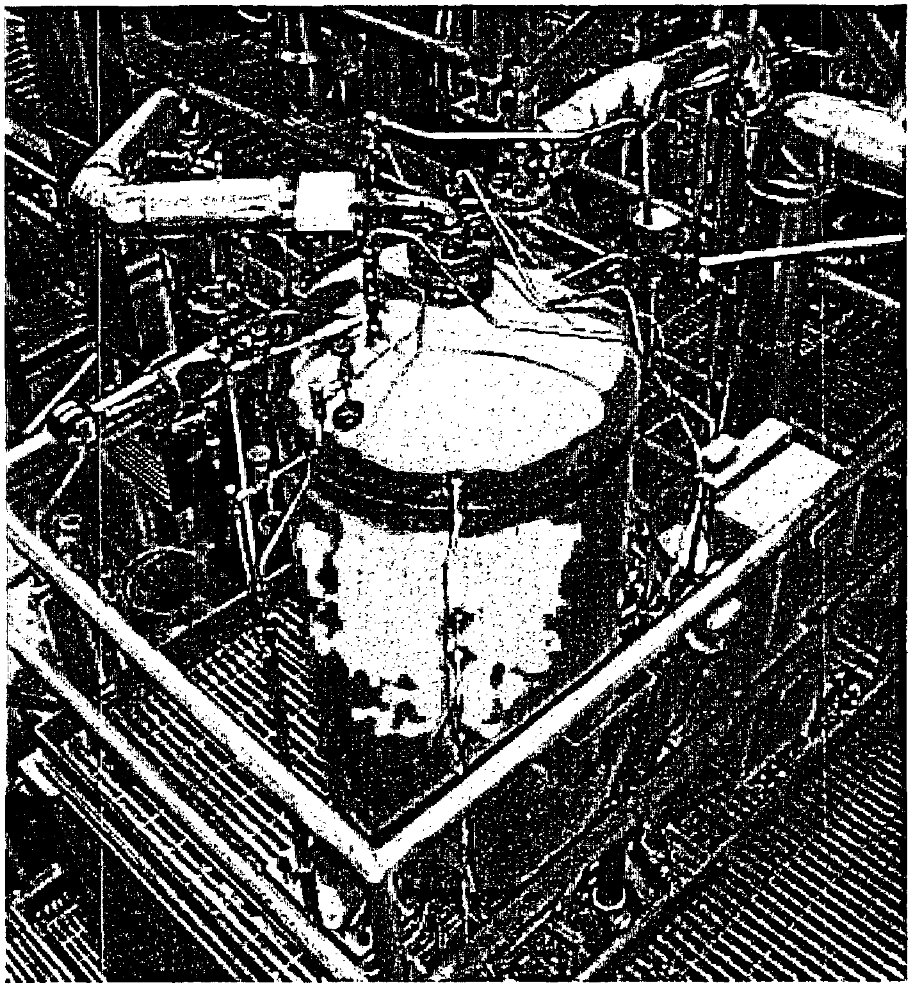

Figure 3-4 Photograph of a Core Makeup Tank

Table 3-5 Component of Core Makeup Tanks

a,b,c

A list of all instruments related to the CMT and related piping is given in Table 3-6.

Table 3-6 List of Core Makeup Tank Instrument Names and Locations			
LDP, FMM, HPS, DP, and PT Cells		Thermocouples	
Identifier	Description	Identifier	Description
DP-501	CMT-01 Injection Differential Pressure	TF-501	CMT-01 Long T/C Rod @ 0.30 in. (0.76 cm) Temperature
DP-502	CMT-2 Injection DP	TF-502	CMT-02 Injection Line Temperature
DP-503	CMT-1 Balance Line DP	TF-503	CMT-01 @ ½ Lower Head Height
DP-504	CMT-2 Balance Line DP	TF-504	CMT-02 Long T/C Rod @ 0.30 in. (0.76 cm) Temperature
FMM-501	CMT-1 Injection Flow	TF-505	CMT-01 @ 20% Volume-Height
FMM-502	CMT-2 CL Balance Line Flow	TF-506	CMT-02 @ ½ Lower Head Height
FMM-503	CMT-1 CL Balance Line Flow	TF-507	CMT-01 Long T/C Rod @ 20.87 in. (53.01 cm) Temperature
FMM-504	CMT-2 Injection Flow	TF-508	CMT-02 @ 20% Volume-Height
LDP-501	CMT-01 NR Uncompensated Water Level (Bottom)	TF-509	CMT-01 Long T/C Rod @ 36.89 in. (93.70 cm) Temperature
LDP-502	CMT-02 WR Uncompensated Water Level	TF-510	CMT-02 Long T/C Rod @ 20.87 in. (53.01 cm) Temperature
LDP-503	CMT-01 NR Uncompensated Water Level (Middle)	TF-511	CMT-01 @ 50% Volume-Height
LDP-504	CMT-02 NR Uncompensated Water Level (Bottom)	TF-512	CMT-02 Long T/C Rod @ 36.89 in. (93.70 cm) Temperature
LDP-505	CMT-01 NR Uncompensated Water Level (Top)	TF-513	CMT-01 Long T/C Rod @ 40.59 in. (103.10 cm) Temperature
LDP-506	CMT-02 NR Uncompensated Water Level (Middle)	TF-514	CMT-02 @ 50% Volume-Height
LDP-507	CMT-01 WR Uncompensated Water Level	TF-515	CMT-01 Long T/C Rod @ 43.41 in. (110.26 cm) Temperature
LDP-508	CMT-02 NR Uncompensated Water Level (Top)	TF-516	CMT-02 Long T/C Rod @ 40.59 in. (103.10 cm) Temperature
LDP-509	CL-3 to CMT-01 Balance Line Uncompensated Water Level	TF-517	CMT-01 @ 75% Volume-Height minus 3.7 in. (9.40 cm)
LDP-510	CL-1 to CMT-02 Balance Line Uncompensated Water Level	TF-518	CMT-02 Long T/C Rod @ 43.41 in. (110.26 cm) Temperature
PT-501	CMT-01 Pressure	TF-519	CMT-01 Long T/C Rod @ 46.23 in. (117.42 cm) Temperature
PT-502	CMT-02 Pressure	TF-520	CMT-02 @ 75% Volume-Height minus 3.7 in. (9.40 cm)
HPS-509-1	CMT-01 CL Balance Line Heat Transfer Coefficient	TF-521	CMT-01 @ 75% Volume-Height

Table 3-6 List of Core Makeup Tank Instrument Names and Locations (cont.)			
LDP, FMM, HPS, DP, and PT Cells		Thermocouples	
Identifier	Description	Identifier	Description
HPS-509-2	CMT-01 CL Balance Line Heater dT above fluid temperature	TF-522	CMT-02 Long T/C Rod @ 46.23 in. (117.42 cm) Temperature
HPS-509-3	CMT-01 CL Balance Line Fluid temperature	TF-523	CMT-01 Long T/C Rod @ 49.05 in. (124.59 cm) Temperature
HPS-512-1	CMT-02 CL Balance Line Heat Transfer Coefficient	TF-524	CMT
HPS-512-2	CMT-02 CL Balance Line Heater dT above fluid temperature	TF-525	CMT-01 @ 1/2 Upper-Head Height
HPS-512-3	CMT-02 CL Balance Line Fluid temperature	TF-526	CMT 2 SPARGER 2\3 TEMP
		TF-527	CMT-01 Long T/C Rod @ 51.87 in. (131.75 cm) Temperature
		TF-528	CMT 2\3% Head Temp
		TF-529	CMT-01 Long T/C Rod @ 56.61 in. (143.79 cm) Temperature
		TF-530	CMT-02 Long T/C Rod @ 51.87 in. (131.75 cm) Temperature
		TF-531	CMT-01 Balance Line @ CMT Inlet Temperature
		TF-532	CMT-02 Long T/C Rod @ 56.61 in. (143.79 cm) Temperature
		TF-533	CMT-01/CL Balance Line @ CL-3 Temperature
		TF-535	CMT-01 Injection Line Temperature
		TF-536	CMT-02/CL Balance Line @ CL-1 Temperature
		TF-537	CMT-01 @ 20% Volume-Height
		TF-538	CMT-02 @ 20% Volume-Height
		TF-539	CMT-01 @ 50% Volume-Height
		TF-540	CMT-02 @ 50% Volume-Height
		TF-541	CMT-01 @ 60% Volume-Height
		TF-542	CMT-02 @ 60% Volume-Height
		TF-543	CMT-01 @ 75% Volume-Height
		TF-544	CMT-02 @ 75% Volume-Height
		TF-546	CMT-02 Balance Line @ CMT Inlet Temperature

Table 3-6 List of Core Makeup Tank Instrument Names and Locations (cont.)			
LDP, FMM, HPS, DP, and PT Cells		Thermocouples	
Identifier	Description	Identifier	Description
		TF-547	CMT-01 Long T/C Rod @ 54.24 in. (137.77 cm) Temperature
		TF-548	CMT-02 Long T/C Rod @ 54.24 in. (137.77 cm) Temperature
		TF-549	CMT-01 Discharge Line Temperature
		TF-550	CMT-02 Discharge Line Temperature
		TF-551	CMT-01 Short T/C Rod (225 degrees) 5.5 in. (13.97 cm) from top
		TF-552	CMT-02 Short T/C Rod (225 degrees) 5.5 in. (13.97 cm) from top
		TF-553	CMT-01 Short T/C Rod (225 degrees) 8.69 in. (22.07 cm) from top
		TF-554	CMT-02 Short T/C Rod (225 degrees) 8.69 in. (22.07 cm) from top
		TF-555	CMT-01 Short T/C Rod (225 degrees) 14.19 in. (36.04 cm) from top
		TF-556	CMT-02 Short T/C Rod (225 degrees) 14.19 in. (36.04 cm) from top
		TF-557	CMT-01 Short T/C Rod (315 degrees) 5.9 in. (14.99 cm) from top
		TF-558	CMT-02 Short T/C Rod (315 degrees) 5.9 in. (14.99 cm) from top
		TF-559	CMT-01 Short T/C Rod (315 degrees) 8.69 in. (22.07 cm) from top
		TF-560	CMT-02 Short T/C Rod (315 degrees) 8.69 in. (22.07 cm) from top
		TF-561	CMT-01 Short T/C Rod (315 degrees) 11.44 in. (29.06 cm) from top
		TF-562	CMT-02 Short T/C Rod (315 degrees) 11.44 in. (29.06 cm) from top
		TF-563	CMT-01 Short T/C Rod (315 degrees) 14.19 in. (36.04 cm) from top
		TF-564	CMT-02 Short T/C Rod (315 degrees) 14.19 in. (36.04 cm) from top

3.4 Passive Residual Heat Remover (PRHR) Heat Exchanger (HX)

The PRHR HX consists of a C-Shape heat exchanger, located inside the IRWST, and two connections to the primary loop. One inlet connection is between the HL-2 ADS 4 tee and the upper PRHR HX manifold on the IRWST, and consists of [ ][a,b,c] pipe. The outlet connection is between the lower PRHR heat exchanger manifold on the IRWST and the CL channel head of SG 2, and also consists of [ ][a,b,c] pipe. The PRHR flow is actuated by an isolation valve (RCS-804) that opens on either "S"-signal, actuation of ADS-1 valve, or on CMT injection valve opening depending on the logic subroutine selected. The PRHR HX is connected to the upper and lower heat exchanger manifolds on the IRWST. It has a total surface area of [ ][a,b,c], and is made up of 88 individual tubes with a [ ][a,b,c] O.D., [ ][a,b,c] wall thickness. See Figure 3-5 for image of the PRHR HX. Refer to PRHS of the As Built drawing set, for a complete description of the piping and elevation of the connection between the PRHR HX and the primary loop.

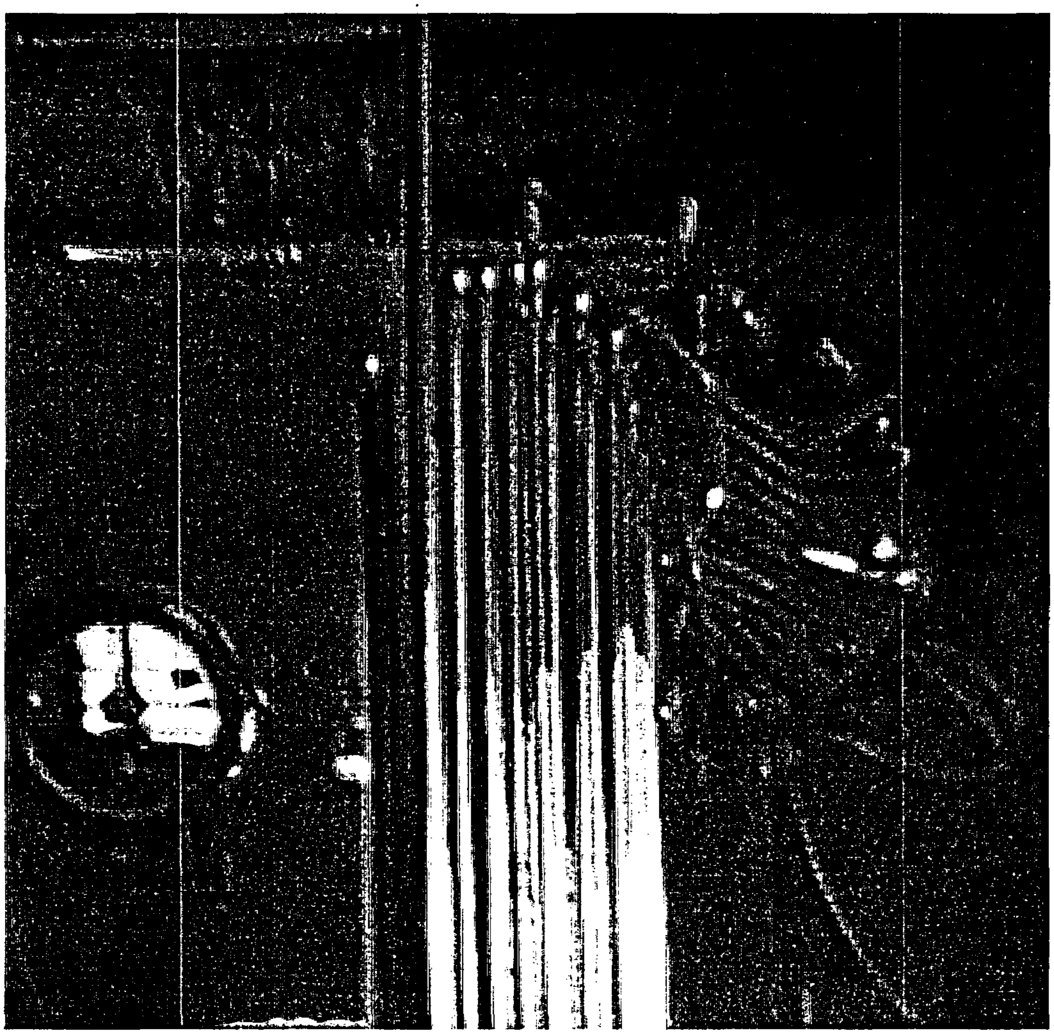

Figure 3-5 View of PRHR HX Located Inside IRWST

Table 3-7 List of PRHR Instrument Names and Locations			
LDP, FMM, and HPS		**Thermocouples**	
Tag Name	**Description**	**Tag Name**	**Description**
FMM-802	PRHR Inlet Flow	TF-803	PRHR HX Inlet Temperature
FMM-804	PRHR Outlet Flow	TF-804	PRHR HX Outlet Temperature
LDP-801	PRHR HX Inlet Head Uncompensated Water Level	TF-805	PRHR HX Long Tube Outlet at Bend Temperature
LDP-802	PRHR HX WR Uncompensated Water Level	TF-806	PRHR HX Short Tube Outlet at Bend Temperature
HPS-801-1	PRHR HX Inlet Heat Transfer Coefficient	TF-808	PRHR HX Short Tube Outlet at Center Temperature
HPS-801-2	PRHR HX Inlet Heater dT Above Fluid Temperature	TF-809	PRHR HX Long Tube at Center Temperature
HPS-801-3	PRHR HX Inlet Fluid Temperature	TF-810	PRHR HX Short Tube Inlet at Bend Temperature
		TF-811	PRHR HX Long Tube Inlet at Bend Temperature
		TF-812	PRHR HX Outlet Head Temperature
		TW-801	PRHR HX Long Tube Outlet
		TW-802	PRHR HX Short Tube Outlet
		TW-803	PRHR HX Long Tube Lower Mid-piece
		TW-804	PRHR HX Short Tube Lower Mid-piece
		TW-805	PRHR HX Short Tube Upper Mid-piece
		TW-806	PRHR HX Long Tube Upper Mid-piece
		TW-807	PRHR HX Short Tube Inlet
		TW-808	PRHR HX Long Tube Inlet

3.5 Accumulators (ACC)

The two ACC tanks are constructed of a [ ]^{a,b,c} long piece of [ ]^{a,b,c} pipe with a [ ]^{a,b,c} pipe cap, and a [ ]^{a,b,c} thick plate. The plate is cut to fit in one end of the pipe, and a pipe cap type end is used to seal the other end. This gives the tank an inner height of [ ]^{a,b,c} and a total volume of [ ]^{a,b,c}, with about [ ]^{a,b,c} being liquid volume and the remaining [ ]^{a,b,c} being gas volume. A list of the components that make up each ACC is given in Table 3-8, while a list of instrument associated with the accumulators is given in Table 3-9.

Table 3-8 Components of Accumulator

a,b,c

Table 3-9 List of Accumulator Instrument Names and Locations

LDP, FMM, DP, and PT Cells		Thermocouples	
Tag Name	**Description**	**Tag Name**	**Description**
DP-401	ACC-1 Injection DP	TF-401	ACC-01 Outlet Temperature
DP-402	ACC-2 Injection DP	TF-402	ACC-02 Outlet Temperature
FMM-401	ACC-1 Injection Flow	TF-403	ACC-01 N_2 Top Temperature
FMM-402	ACC-2 Injection Flow	TF-404	ACC-02 N_2 Top Temperature
LDP-401	ACC-01 Uncompensated Water Level	TF-405	ACC-01 Injection Line Temperature
LDP-402	ACC-02 Uncompensated Water Level	TF-406	ACC-02 Injection Line Temperature
PT-401	ACC-01 Pressure		
PT-402	ACC-02 Pressure		

Each ACC is connected to a DVI line by [ ]^{a,b,c} O.D., [ ]^{a,b,c} I.D. tubing. The fluid flow initiates from an ACC to its respective DVI line by means of a check valve (RCS-423/424), which opens when plant pressure becomes less than the pressure in the ACC (approximately [ ]^{a,b,c}). Refer to ACC 1 and ACC 2 of the As Built drawing set for a complete description of the piping and elevation of the connection between the ACCs and the DVI. See Figure 3-6 for an image of an ACC.

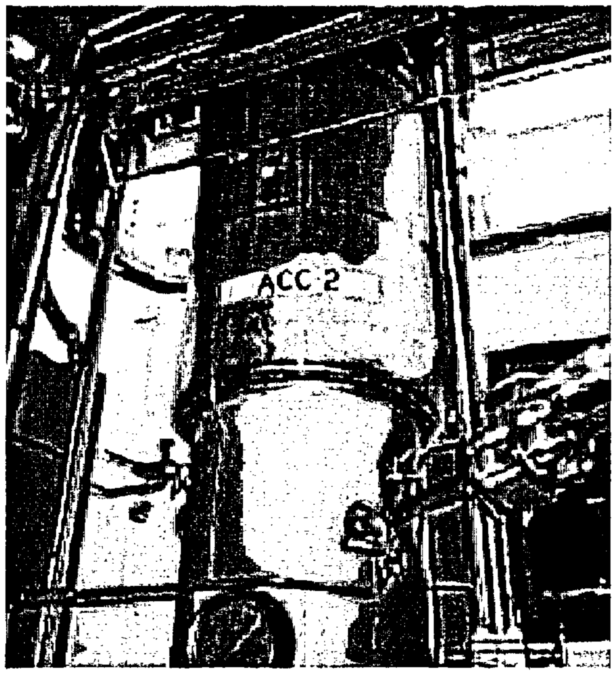

Figure 3-6 Photograph of One of APEX Accumulators

3.6 Containment Sump

The primary containment sump tank is constructed of SS 304 plate with a thickness of [ ]^{a,b,c}, and an inner diameter of [ ]^{a,b,c} in the cylindrical section. The cylindrical section is capped with [ ]^{a,b,c} elliptical ends with wall thickness of [ ]^{a,b,c}. The outside tank height including the elliptical ends is [ ]^{a,b,c}. The sump tank total volume is [ ]^{a,b,c}.

The primary sump tank is connected to the ADS 4 separators, the secondary sump, the break separator, DVI 1 and 2, and the steam exhaust header. The sump to collects all liquid flow from the break and ADS 4 lines. Two containment sump recirculation lines are connected to the bottom of the primary sump and provide a recirculation path to the RPV via the DVI lines. Each line consists of an isolation valve with a parallel line with check valves. The isolation valves (CSS-909/910) are open on decreasing IRWST level [ ]^{a,b,c}. A secondary sump is also provided and models containment sump volumes that are not available for long-term circulation. A curb overflow is simulated between the primary and secondary sumps by a Weir plate. The secondary sump volume is [ ]^{a,b,c}. See Table 3-10 for components of the primary sump and Table 3-11 for the secondary sump components. A list of instruments associated with the primary and secondary sumps is given in Table 3-12. Refer to 787-PS01 of TIC drawings and 787-BAM 1 of the As Built drawing set for a complete description of the primary sump tank.

Table 3-10 Components of Primary Sump

a,b,c

Table 3-11 Components of Secondary Sump

a,b,c

Table 3-12 List of Sump Instrument Names and Locations			
LDP, FMM, FVM, LCT, and PT Cells		Thermocouples	
Tag Name	Description	Tag Name	Description
FMM-901	Primary Sump-1 Recirculation Injection Flow	TF-901	Primary Sump Inlet from Fill Line Temperature
FMM-902	Primary Sump-2 Recirculation Injection Flow	TF-902	Secondary Sump Bottom Temperature
FMM-905	Break Separator Loop Seal Flow	TF-903	Primary Sump Bottom Temperature
FVM-903	Primary Sump Steam Exhaust Flow	TF-904	Primary Sump/DVI-2 Injection Line Temperature
LDP-901	Primary Sump Uncompensated Water Level	TF-905	Primary Sump @ Secondary Sump Crossover Level Temperature
LDP-902	Secondary Sump Uncompensated Water Level	TF-906	Primary Sump Exhaust Temperature
LDP-903	CRT Uncompensated Water Level	TF-907	Primary Sump @ Top Temperature
LDP-905	Break Separator Uncompensated Water Level	TF-909	Primary Sump/DVI-1 Injection Line Temperature
PT-901	Primary Sump Pressure	TF-910	CRP Discharge to Primary Sump Temperature
LCT-901	Primary Sump Weight	TF-911	CRP Discharge to IRWST Temperature
LCT-902	Secondary Sump Weight	TF-912	Break Separator Loop Seal Temperature
		TF-913	Break Separator Steam Outlet Temperature
		TF-914	CRT Outlet Temperature

3.7 Line Dimensions and Resistance

For a summary of the piping in the safety systems of the APEX facility, refer to Table 3-13. See Table 3-14 for a summary of measured line resistances of the passive safety system components of the APEX facility.

Table 3-13 Summary of Safety System Line Dimensions

a,b,c

Table 3-14 Line Resistances for Passive Safety Systems

a,b,c

4.0 INSTRUMENTATION, CONTROL, AND POWER SYSTEMS

This section describes the instrumentation, control, and power systems of the APEX test facility. This section will also discuss the data acquisition system, instrument devices, and associated control logic.

4.1 Instrumentation Description

The APEX test facility is equipped with approximately 622 instrument channels to capture the transient behavior of the safety systems. The APEX facility includes the following different types of instrumentation channels:

- Thermocouples (TF/TR/TH/TW) are used to measure fluid, heater, and wall temperatures. Premium thermocouples with controlled purity thermocouple wire were incorporated.
- Magnetic flow meter (FMM) - Magnetic flow meters are incorporated to measure single phase liquid flows around the plant.
- Vortex flow meter (FVM) – Vortex shedding flow meters are used to measure single phase vapor flow rates.
- Pressure transducers (PT) are used to measure the static pressures in various tanks and pipes within the facility.
- Differential pressure (LPD, DP) transducers are used to measure liquid levels in various tanks and pipes. The differential pressure cells are also used to measure pressure drops.
- Heated phase switches (HPS) are used to determine the fluid phase at various points inside system piping. Each HPS measures: fluid temperature, ΔT between the fluid and the heater, and a relative heat transfer coefficient.
- Load cell transducers (LCT) are incorporated to measure the liquid mass inside the IRWST, the Primary Sump, and the Secondary Sump.
- Heater power (KW) – Power to the core is measured with four power meters. The power applied to the Pressurizer heaters is measured by an addition power meter.
- Level transducer (LT) – A capacitance probe is used in the reactor vessel to measure collapsed liquid level.

Instrumentation channels are subdivided into 10 different groups based on a particular location. The numbering system is as follows:

Table 4-1 Instrument Tag Locations	
Channel Name	**Location**
xx-000s	Feed, Main Steam
xx-100s	Reactor Pressure Vessel
xx-200s	Primary Loop
xx-300s	SG
xx-400s	ACC
xx-500s	CMTs
xx-600s	PZR, ADS 1-3
xx-700s	IRWST
xx-800s	PRHR, CVS, RNS
xx-900s	Sump, ADS 4-1, ADS 4-2, and Break System

4.2 Data Acquisition

There are approximately 622 instrumented channels in the APEX test facility. The Data Acquisition System (DAS) writes the data into a single large database. The advantages of using a single database over individual test files are:

- Better management and maintenance.
- To enable retrieval to be independent of storage (i.e., the data is stored every one second, but the database can be queried at another resolution, say every 5 seconds.) This provides a very powerful and flexible retrieval capability.

The single database also allows for easy comparisons between multiple tests since the data is stored together in a large database.

The DAS is manufactured by National Instruments (NI) and uses off the shelf software. The 622 channels of signal are from many types of instruments – thermocouples, differential pressure cells, flow meters, and the like. The signal type may be 4-20 mA current signal or 1-5 VDC or 0-10 VDC voltage signal or the millivolt signal originating from thermocouples. The instruments are connected to several terminal boards. Each terminal board can accept any combination of J, K, and T type of thermal couple and up to 32 channels of inputs with their own cold junction compensation. These terminal boards are also used for other types of signal inputs. Each terminal board is connected to one analog input module that rests within a chassis which contains 12 modules. The DAS use three chassis to acquire the data. The signals from the chassis are then transferred to a computer that is equipped with a multifunction I/O board. Basically, the multifunction I/O boards switch their input between 622 channels at high speed to sample all input channels. The data for APEX will typically be sampled at a rate of one Hertz per channel.

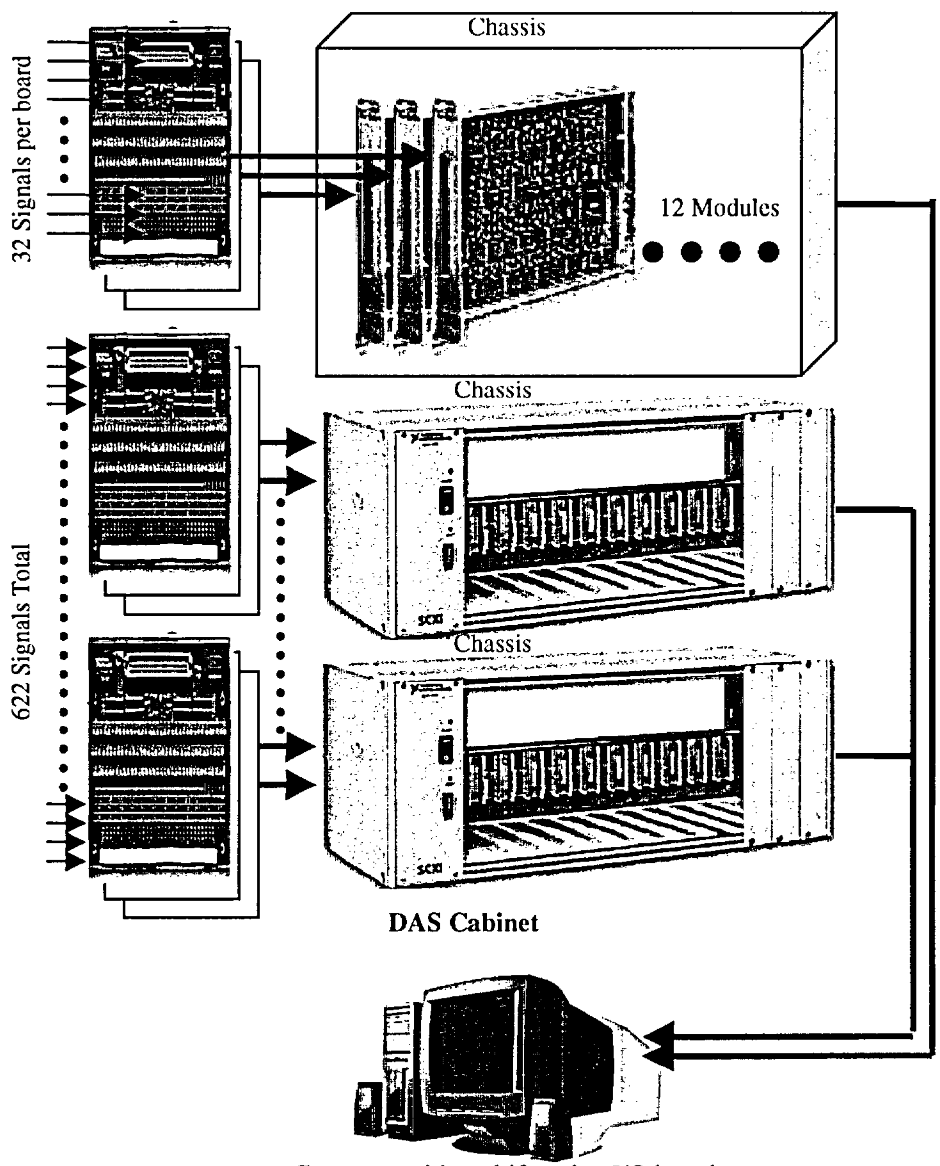

Figure 4-1 Data Acquisition System Hardware Overview

All the data from input channels are acquired by National Instruments NI-DAQ hardware/software and is then converted into engineering units. The real-time data are sampled and stored in National Instruments Citadel database at one time per second per channel. The Citadel is a proprietary database used for process data. OSU developed an export program to query the Citadel database and format the data file in ASCII text and NRC Data Bank binary file formats.

National Instruments DIAdem 8.1 trending package software is used for data plotting for generating reports. DIAdem is capable of manipulating large data sets of more than a billion data points in up to 65,000 columns.

4.3 Control System and Control Logic

The APEX Test Facility Control Logic System includes various field process transmitters, operator switches, an OMRON Programmable Logic Controller (PLC), a set of Fischer & Porter Process Controllers (PCs), and a supervisory host computer.

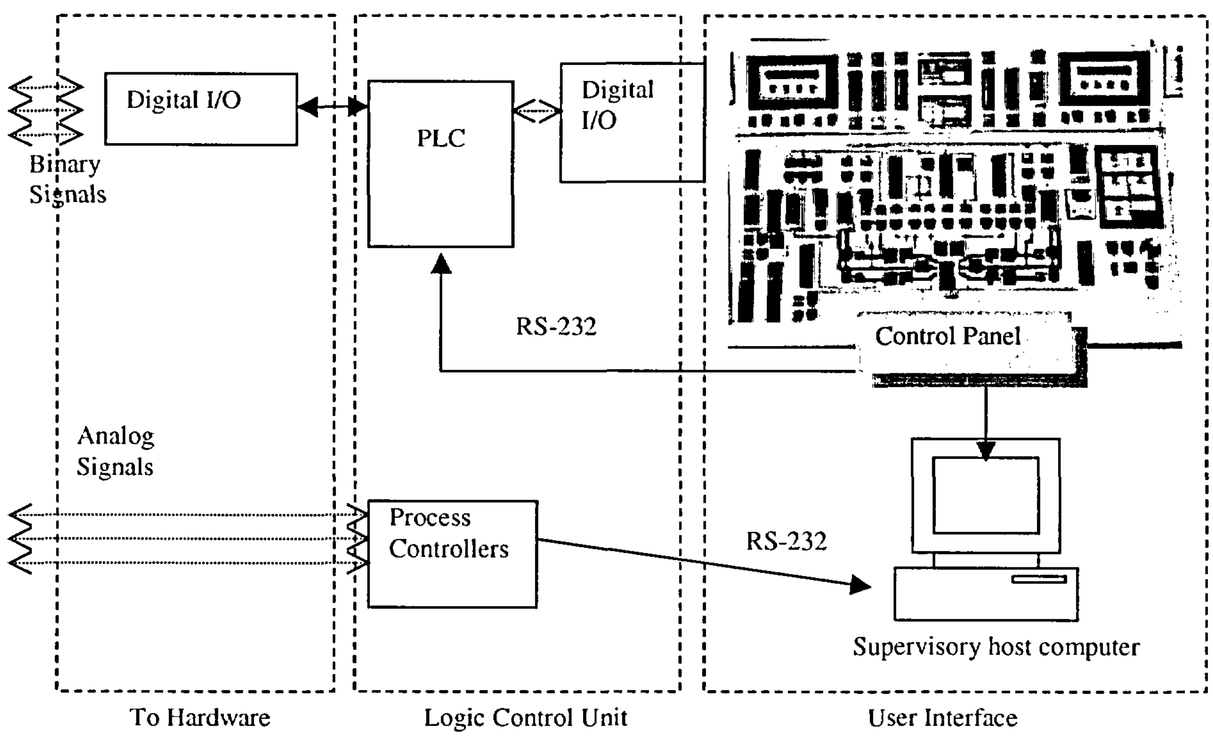

Figure 4-2 Control System Interface

The control system functions in three basic parts:

1. The PLC performs all binary logic functions for safety, sequencing, and operational control.

2. The PCs perform all dynamic (analog) process controls for smooth operation of variable control devices.

3. The supervisory system provides a graphical computer interface between the operator and the facility.

The PLC consists of a central processor for program execution, power supply, two local racks of digital I/O and several remote I/O racks located throughout the facility. All inputs are sensed as 24 VDC signals. All outputs are driven by a 24 VDC supply to energize pneumatic valves, pump motor starters, control panel lights and alarms, and the like.

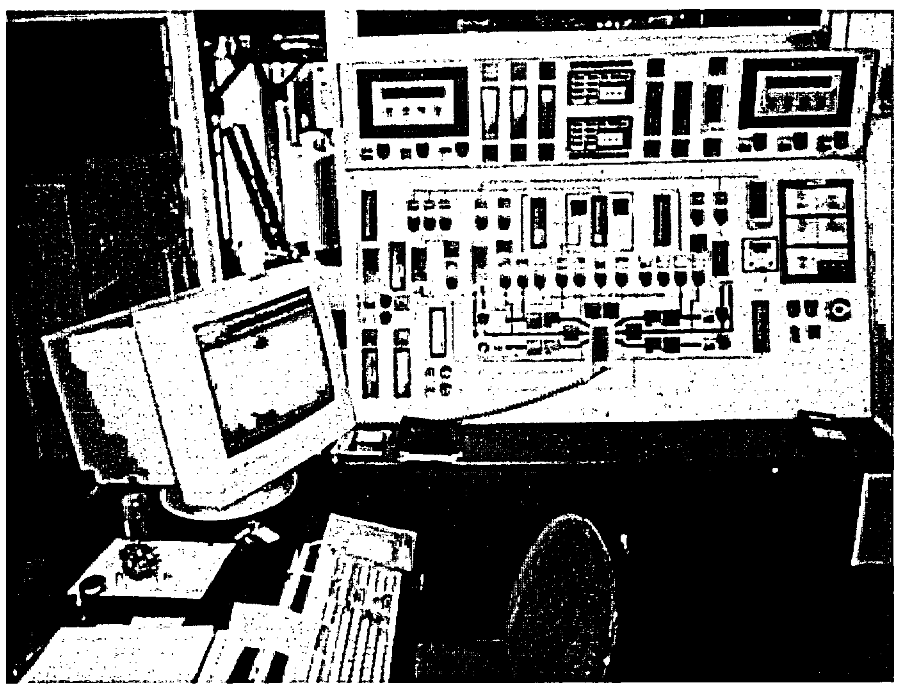

Figure 4-3 Photograph of Control Panel

The process control system consists of seven dedicated PCs with a total of 40 analog inputs and 20 analog outputs. Analog inputs are used to monitor the process, either directly or as a calculated variable. They include tank level, system pressure, pump flow rate, and applied heater power. The controller performs a series of calculations to determine the likely state of the process and adjusts the analog output of the controlling device to maintain the process within defined parameters. The controlling devices include valves, power SCR's and variable speed pump controllers. The data acquisition system and the control computer are connected by a high speed local area network.

There are six test logic routines implemented in APEX logic:

1. Station Blackout Routine
2. Small-Break LOCA Routine
3. Large-Break LOCA Routine
4. Inadvertent ADS Initiation Routine
5. Full-Pressure ADS Routine
6. Natural Circulation Routine

The test logic routines are described below.

- Station Blackout Routine Logic

a,b,c

- Small-Break LOCA Routine Logic

a,b,c

- Large-Break LOCA Routine Logic

(Much the same as Small-Break LOCA routine logic except the test initialization)

a,b,c

- Inadvertent ADS Initiation Routine Logic

a,b,c

- Full-Pressure ADS Routine Logic

a,b,c

- Natural Circulation Routine

This routine permits operation of the reactor controller in manual or automatic mode, with or without RCPs and with no "S"-signal or automatic trip functions. This routine allows flexibility to custom-tailor a test without requiring extensive re-programming.

The setpoint table lists each bi-stable device and their associated set/reset points. Most of these values can be readily modified by the operator and in some cases vary among the different logic routines. The table contains the tag name of the device, the specific point (e.g., HH for High-High), the set/reset points applicable to the logic routine, and the logic diagram sheet number(s) showing the device.

Table 4-2 APEX Controller Set Point Values

a,b,c

Table 4-2 APEX Controller Set Point Values (cont.)

a,b,c

Table 4-2 APEX Controller Set Point Values (cont.)

a,b,c

Table 4-2 APEX Controller Set Point Values (cont.)

a,b,c

- Automatic Actuation of PRHR and CMT on S-Signal

a,b,c

- Automatic Actuation of ADS 1-4 on CMT Level or Timers

a,b,c

- Automatic Control of SG Pressure, Liquid Water Level, Feed Water Flow, and Main Steam Flow

a,b,c

- Automatic Control of PZR Pressure and Level

a,b,c

- Programmed Reactor Decay Power and Control of Core Exit Temperatures

a,b,c

Input Signal	Output signal to

- Programmed CVS and RNS Pump Flow Rates

a,b,c

All control actions, such as valve operation, pump starts, and safety signals are archived as sequence-of-events by the Wonderware software package.

4.4 Power System

The main purpose of the power system is to provide up to 1 megawatt of power to the Rx and PZR heater rods. Power comes from the local power grid at a voltage of 20,800 volts and is stepped down to a distribution voltage of 480 volts, three phase.

From the 480 volt distribution power, one line (three-phase, max current≈100A) is used for the pumps in the APEX facility (RCP-1 to RCP4, MFP, CVSP, RNSP, CRP, and seal WTR fan). Another line (three-phase, max current ≈200A) provides the power for trace heaters. The three remaining lines are for the two Rx heater rod groups (three-phase, 500 kW max each line) and for PZR heater (three-phase, 20 kW max).

Each of the heater power lines has:

- A breaker – manually turn on/off the power
- A fuse – for circuit protection
- A contactor – remotely turn on/off the power
- A phase angle fired silicon control rectifier (SCR) – adjust the power level (SCR-1 and SCR-2 for Rx heater group 1 and 2, SCR-3 for PZR heater)

During the test, the contactor controls the ON/OFF of the heater and the SCR signals are used for adjusting heater power level. The reactor heater rod SCRs in conjunction with the heater controller allow the APEX facility to simulate decay power by continually adjusting the reactor power level set point to follow the desired decay curve. See Figure 4-4 for a photograph of the SCR cabinet and Figure 4-5 for a simplified sketch of the main power distribution system.

Figure 4-4 Photograph of SCR Cabinet

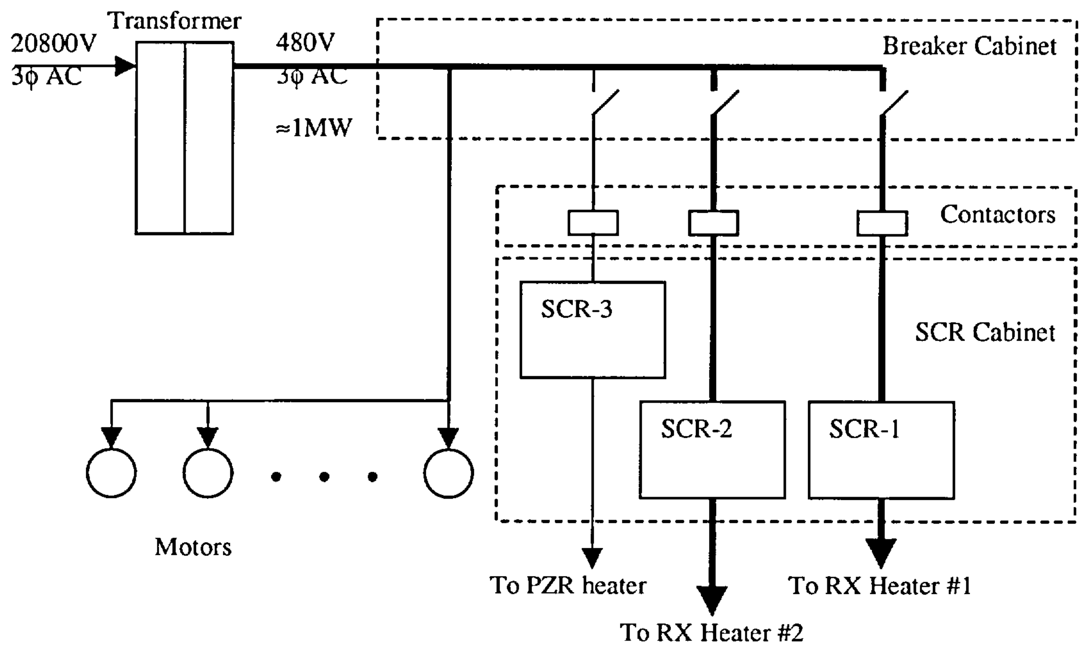

Figure 4-5 Main Power System Simple Layout

4.5 Break and ADS Measurement System (BAMS)

The Break and ADS Measurement System (BAMS) is used to measure two-phase volumetric flow rates from the break(s) and four stages of ADS. All the steam lines from the break separator, the ADS 4 separators, the IRWST, and the primary sump all feed into BAMS header and eventually vent via the exhaust header. The break separator and the ADS 4 separators have a maximum working pressure of [ ]^{a,b,c} at [ ]^{a,b,c}, while the ADS 1-3 separator has a maximum working pressure of [ ]^{a,b,c} at [ ]^{a,b,c}. All of the steam lines and moisture separators are heated with strip heaters to prevent condensation. Steam volumetric flow rate, pressure, and temperature are measured by vortex flow meters, pressure cells, and thermocouples respectively (see OSU 600901).

The BAMS system includes:

- Break separator
- Two ADS 4 separators
- ADS 1-3 separator

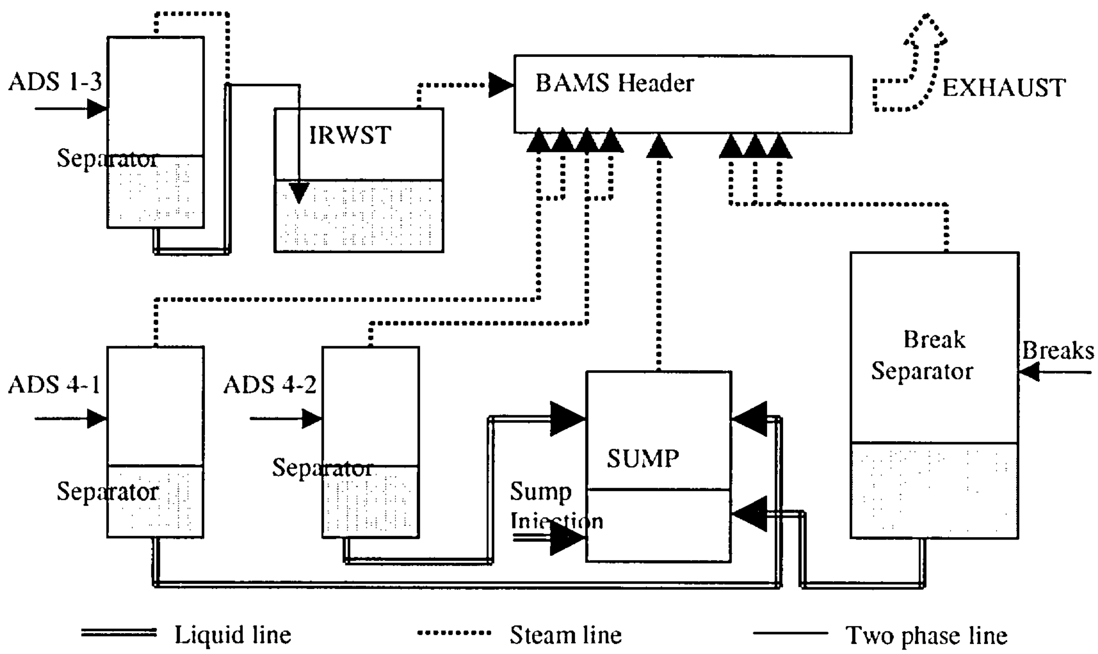

Figure 4-6 BAMS System Layout

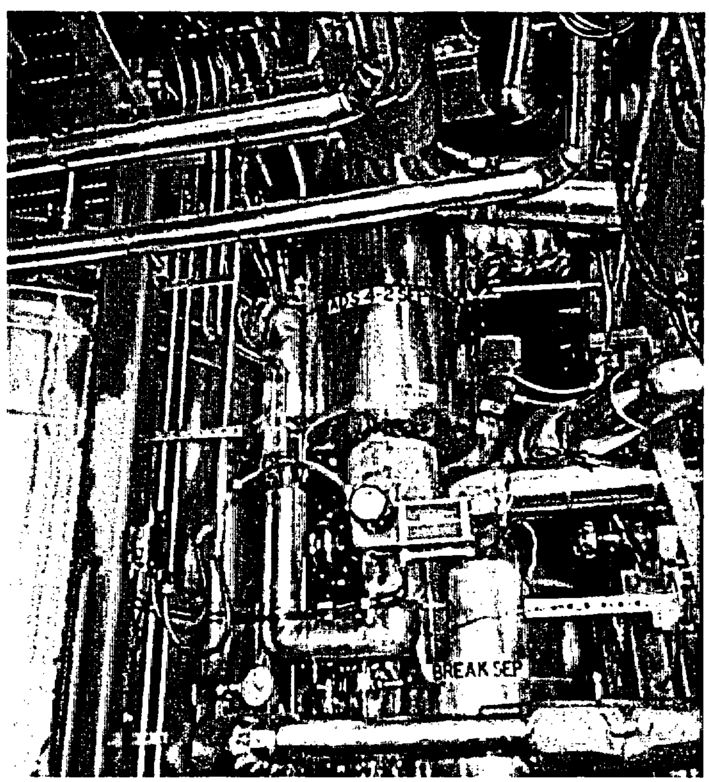

Figure 4-7 Photograph Showing ADS4-2 and Break Separator

The Apex Test Facility can model several different break locations (details in DWG OSU 600904):

1. CL-3 bottom break (TS-205 actuates)

2. CL-3 top break (TS-201 & T-205 both actuates)

3. Single-ended DVI break (TS-202 actuates, pressure equalization line open during warm-up, closed prior to break)

4. Single-ended CMT balance line break (TS-203 actuates, pressure equalization line open during warm-up, closed prior to break)

5. HL-2 bottom break (TS-204 actuates)

6. CL-4 bottom break (TS-206 actuates)

7. Double-ended CMT balance line break (TS-203 and TS-202 actuates)

8. Double-ended DVI break (TS-203 and TS-202 actuates)

The two-phase flow that exits the break is piped into the break separator via a [ ]^{a,b,c} line. The primary purpose of the break separator is to separate the steam and liquid phase of two phase flow for the convenience of measurement. The break separator is a [ ]^{a,b,c} diameter, [ ]^{a,b,c} high cylinder (See OSU 930103 sheet 2). Water/steam mixture enters through the middle and passes through a cyclone separator. The separated steam exits the top of the separator via a [ ]^{a,b,c} pipe, while the liquid is collected and allowed to drain out of the bottom of the separator via a [ ]^{a,b,c} pipe through a loop seal and into the primary sump. The wall of the separator is heated by [ ]^{a,b,c} long strip heater to prevent steam condensation inside the separator.

The break separator steam outlet line is divided from a [ ]^{a,b,c} pipe into 3 smaller parallel paths: [ ]^{a,b,c} and are recombined before the exhaust. The steam flow is routed through one of these three paths depending on the flow rate expected. Each of these paths is controlled by an air operated logic ball valve and measured by a vortex flow meter. The reason to do so is to control the separator liquid level within the desired range to keep the steam and liquid goes to the right outlet. If the steam line size is too small for a given flow rate, the increased pressure will push the water out of the loop seal and there will be a two phase mixture in the liquid line which cannot be measured. If the selected steam line is too large, then it is difficult to get an accurate measure of the steam flow rate when the flow rate is small. The ADS 4 separator steam line has the similar design, but uses only two paths (see OSU 600901). The primary sump and secondary sump are used to simulate the containment and are described in detail in Chapter 3.6.

The exiting mixture flow from each ADS 4 valve is directed into its own separator. The separators are [ ]^{a,b,c} high and [ ]^{a,b,c} O.D. The two ADS 4 separators are similar in design to the break separator (See OSU 930103 sheet 1). The steam exiting the separators can be directed through a [ ]^{a,b,c} or a [ ]^{a,b,c} pipe depending on the expected flow rate. The reasoning behind the use of different size steam lines is the same as for the flow out of the break separator. The liquid phase from each ADS 4 separator collected and directed through a loop seal and into the primary sump.

ADS 1-3 separator is a [ ]^{a,b,c} OD, [ ]^{a,b,c} high cylinder. The exiting mixture flow from ADS 1-3 valves is directed into the ADS 1-3 separator through a [ ]^{a,b,c} inlet. The liquid flow exits the bottom of the separator in a [ ]^{a,b,c} pipe, while the steam flow exits the separator via a [ ]^{a,b,c} pipe. The steam exits the separator through a 4 in. pipe at the opposite side of the inlet. The steam volumetric flow rate is measured by a vortex flow meter (FVM-601). Liquid phase is directed out of the separator via a [ ]^{a,b,c} pipe at the bottom of the separator and measured by a magnetic flow meter. The steam and liquid phase are finally recombined and injected into IRWST via a sparger. (Details are in DWG A-30597.)

In the prototype, the steam phase that exits the break will condense on the wall of containment and drains back to IRWST or sump. In the test facility, the steam phase is vented to the atmosphere. To compensate for the mass loss due to steam exhaust into the environment, the containment condensate return system is available to inject fluid into the IRWST or sump at the same mass flow rate of the vented steam if desired. The condensate return system is fed by the Feedwater Storage Tank (FST) into the Condensate Return Tank (CRT) in which the water is preheated. The CRT has a capacity of approximately [ ]^{a,b,c} and contains [ ]^{a,b,c} heaters to preheat the water prior to injection into the IRWST or the primary sump. The outlet water temperature is measured by a thermocouple and the measurement is feedback to the CRT heaters to maintain proper outlet temperature. The liquid is pumped from the CRT by means of the condensate return pump (CRP) through either a recirculation line with the line resistance controlled by an orifice plate or to the IRWST or the primary sump via motor-operated valves (CCS-928/927).

Table 4-3 List of ADS 4-1/4-2, and Break Separator Instrument Names and Locations

LDP, FVM, FMM, DP, and PT Cells		Thermocouples	
Tag Name	**Description**	**Tag Name**	**Description**
DP-905	Break Separator Entrance DP	TF-908	Break Separator Inlet Temperature
FMM-905	Break Separator Loop Seal Flow	TF-910	CRP Discharge to Primary Sump Temperature
FVM-901	BAMS HDR 6 in. Line Steam Flow	TF-911	CRP Discharge to IRWST Temperature
FVM-902	BAMS HDR 10 in. Line Steam Flow	TF-912	Break Separator Loop Seal Temperature
FVM-904	Break separator 3 in. line steam flow	TF-913	Break Separator Steam Outlet Temperature
FVM-905	Break Separator 6 in. Line Steam Flow	TF-914	CRT Outlet Temperature
FVM-906	Break Separator 8 in. Line Steam Flow	TF-915	Break Separator 6 in. Steam Line Temperature
LDP-903	CRT Uncompensated Water Level	TF-916	BAMS Header 10 in. Steam Line Temperature
LDP-905	Break Separator Uncompensated Water Level	TF-917	BAMS Header Temperature
PT-902	BAMS Header Pressure	TF-918	Break Separator 8 in. Steam Line Temperature
PT-905	Break Separator Pressure	TW-905	Break Separator Wall Temperature

5.0 BALANCE OF PLANT

Several of the AP1000 non-safety systems were included in the APEX-1000 facility. These include the CVS, the RNS, the SG feedwater system, the main steam system, and the water purification system. These non-safety systems were designed and constructed to meet the necessary functional requirements for testing. The pipe routings and relative locations within the APEX facility are not necessarily prototypic of the AP1000.

5.1 Chemical and Volume Control System (CVS)

The CVS is used to maintain proper water chemistry in the primary coolant for a full size plant. The CVS pump is a Goulds 3 stage centrifugal pump [ ][a,b,c]. See Table 5-1 for a list of instruments related to the CVS. In the APEX facility, the CVS pump is used for five main purposes, which are as follows:

1. Maintenance of fluid during startup
2. Can model AP1000 operation if desired
3. Normal supply of makeup water to the APEX facility
4. Used for hydrostatic testing
5. Backup pump for the MFP

Table 5-1 CVS Instrument Names and Locations

FMM, PT Cells, and Thermocouples	
Tag Name	**Description**
FMM-801	CVSP Discharge Flow
PT-801	CVSP Discharge Pressure
TF-801	CVSP Discharge Temperature

5.2 Normal Residual Heat Removal System (RNS)

The RNS pump draws water from IRWST or primary sump and injects into the DVI line and provides makeup water under low pressure conditions. The RNS pump is used to fill the core makeup tanks as well as the ACCs prior to performing a test. See Table 5-2 for a list of instruments related to the RNS.

Table 5-2 RNS Instrument Names and Locations			
FMM and PT Cells		Thermocouples	
Tag Name	Description	Tag Name	Description
FMM-803	RNSP to DVI-2 Flow	TF-802	RNSP Discharge Temperature
FMM-805	RNSP Discharge Flow	TF-813	RNSP Discharge to DVI-1 Temperature
PT-802	RNSP Discharge Pressure	TF-814	RNSP Discharge to DVI-2 Temperature

The performance curve for the RNS pump {CR4-100N (5.0 HP (3.73 kW))} is shown in Figure 5-1.

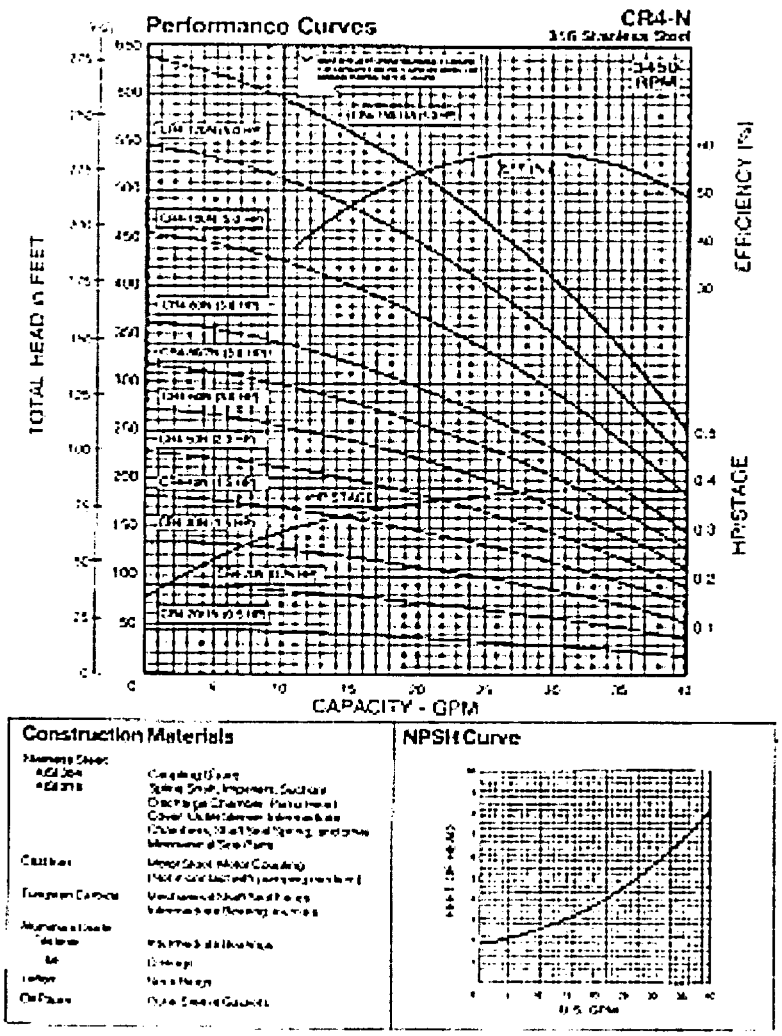

Figure 5-1 RNS Pump Performance Curves

5.3 Feed Water System

The purpose of the feed water system is to provide water to the SG. The feed water system consists of the demineralization system (DI), the feed storage tank (FST), and the main feed pump (MFP) (P&ID drawing in DWG 600002).

The FST is a stainless steel cylinder with a diameter of [ ][a,b,c] and a height of [ ][a,b,c]. The wall thickness of FST is [ ][a,b,c]. The FST stores water from the demineralization system.

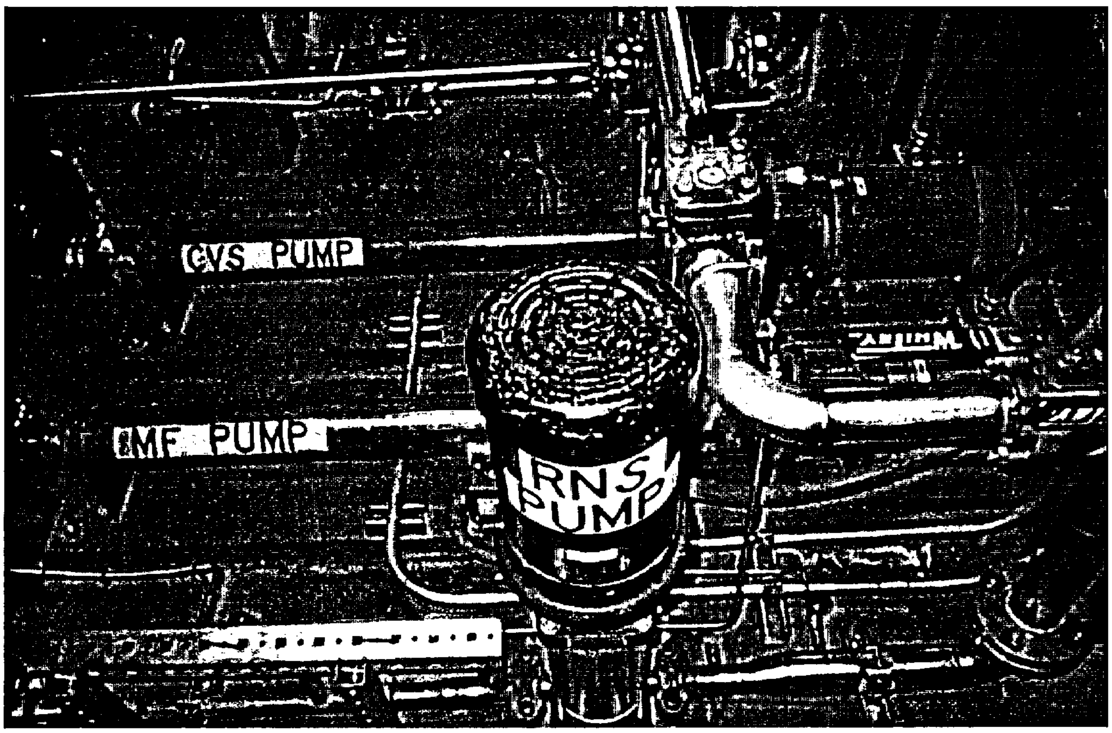

Figure 5-2 Image of RNS, CVS, and MF Pumps

For main feed flow path, the MFP takes water from the FST and pumps it into both SGs. The MFP is a Goulds 3 stage centrifugal pump [ ][a,b,c]. The pump curve is at the end of this section. There is a magnetic flow meter (FMM-001 or FMM-002) and a motor-driven valve (MF-011 or MF-012) in each feed line respectively to monitor and control the feed water flow.

When the steam exits the SG, there are two possible paths for the steam to go:

1. One path is controlled by a normally open air-operated ball valve (MS-001 for SG1 and MS-002 for SG2) and monitored by a vortex flow meter (FVM-001 for SG1 and FVM-002 for SG2).

2. The other path is controlled by a normally closed air-operated ball valve (MS-009 for SG1 and MS-010 for SG2) and monitored by a vortex flow meter (FVM-009 for SG1 and FVM-010 for SG2).

Both of these lines will eventually exit the building through the steam exhaust. The difference of the two lines is that the first path goes through the turbine simulation path with a motor-operated logic ball valve (MS-008) and monitored by a vortex flow meter (FVM-003), and the other is used for the startup of the facility. (See OSU 600002)

Table 5-3 List of FST, MFP, SG Steam Vent Instrument Names and Locations

LDP, FMM, FVM, and PT Cells		Thermocouples	
Tag Name	**Description**	**Tag Name**	**Description**
FMM-001	SG-01 Feed Flow	TF-005	Lab Ambient Temperature @ Ground Level
FMM-002	CL-2 Loop Flow	TF-006	Lab Ambient Temperature @ 2nd Level
FVM-001	SG-1 Main Steam Flow	TF-007	Lab Ambient Temperature @ 3rd Level
FVM-002	SG-2 Main Steam Flow	TF-009	SG-01 PORV Line Temperature
FVM-003	Main Steam Combined Flow	TF-010	SG-02 PORV Line Temperature
FVM-009	SG-01 PORV Steam Flow	TF-301	TF-301/SG-01 (via Signal Conditioner)
FVM-010	SG-02 PORV Steam Flow	TF-310	TF-310/SG-02 (via Signal Conditioner)
LDP-001	FST Level	TF-311	SG-01 Feed Header Temperature
PT-001	MFP Discharge Pressure	TF-312	SG-02 Feed Header Temperature
PT-002	MS Header Pressure		
PT-003	Lab Barometric Pressure		
PT-009	SG-01 PORV Line Pressure		
PT-010	SG-02 PORV Line Pressure		
PT-301	SG-01 Pressure		
PT-302	SG-02 Pressure		

a,b,c

Figure 5-3 Main Feed Pump Characteristic Curves

5.4 Water Purification System

The water source of the feed water system comes from portable water. The demineralization system (DI) purifies incoming potable water for the usage of the secondary loop. The water first passes through two parallel resin traps (resin trap 1 and 2). It is then demineralized by four demineralization tanks which are arranged into two parallel groups (demineralization bank 1 and 2). The water then passes through two additional resin traps (resin trap 3 and 4) after the demineralization tanks. The flow rate is then measured by a vortex flow meter (FVM-004) and then an injection line allows chemicals to be injected from chemical addition tank. The chemicals that are added to the water include ammonium hydroxide (NH_4OH) and NALCO 1254. Ammonium hydroxide is used to reduce the pH is the system to about [ ]^{a,b,c} to minimize corrosion of the components. NALCO 1254 is an additive to prevent buildup of sludge within the system. After all the treatment, the feed water is sent to the feed storage tank (FST) (see OSU 600002 sheet 2).